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| APPLICATION NO. | FILING DATE | FIRST NAMED INVENTOR | ATTORNEY DOCKET NO. | CONFIRMATION NO. |
|-------------------------|-------------|-----------------------|---------------------|------------------|
| 13/591,162 | 08/21/2012 | Christopher H. Cooper | 1112.0001-05000 | 1832 |
| 68540 | 7590 | 02/11/2014 | EXAMINER | |
| O'BRIEN JONES, PLLC | | | BURKE, SEAN P | |
| 1951 Kidwell Drive | | | ART UNIT | |
| Suite 740 | | | PAPER NUMBER | |
| Tysons Corner, VA 22182 | | | 3646 | |
| | | | NOTIFICATION DATE | DELIVERY MODE |
| | | | 02/11/2014 | ELECTRONIC |

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

Notice of the Office communication was sent electronically on above-indicated "Notification Date" to the following e-mail address(es):

docketing@obrienjones.com

| | | |
|------------------------------|------------------------|---------------------|
| Notice of Abandonment | Application No. | Applicant(s) |
| | 13/591,162 | COOPER ET AL. |
| | Examiner | Art Unit |
| | SEAN P. BURKE | 3646 |

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address--

This application is abandoned in view of:

1. ☒ Applicant's failure to timely file a proper reply to the Office letter mailed on 12 July 2013.
 - (a) ☐ A reply was received on _____ (with a Certificate of Mailing or Transmission dated _____), which is after the expiration of the period for reply (including a total extension of time of _____ month(s)) which expired on _____.
 - (b) ☐ A proposed reply was received on _____, but it does not constitute a proper reply under 37 CFR 1.113 to the final rejection. (A proper reply under 37 CFR 1.113 to a final rejection consists only of: (1) a timely filed amendment which places the application in condition for allowance; (2) a timely filed Notice of Appeal (with appeal fee); or (3) a timely filed Request for Continued Examination (RCE) in compliance with 37 CFR 1.114).
 - (c) ☐ A reply was received on _____ but it does not constitute a proper reply, or a bona fide attempt at a proper reply, to the non-final rejection. See 37 CFR 1.85(a) and 1.111. (See explanation in box 7 below).
 - (d) ☒ No reply has been received.

2. ☐ Applicant's failure to timely pay the required issue fee and publication fee, if applicable, within the statutory period of three months from the mailing date of the Notice of Allowance (PTOL-85).
 - (a) ☐ The issue fee and publication fee, if applicable, was received on _____ (with a Certificate of Mailing or Transmission dated _____), which is after the expiration of the statutory period for payment of the issue fee (and publication fee) set in the Notice of Allowance (PTOL-85).
 - (b) ☐ The submitted fee of \$_____ is insufficient. A balance of \$_____ is due.
The issue fee required by 37 CFR 1.18 is \$_____. The publication fee, if required by 37 CFR 1.18(d), is \$_____.
 - (c) ☐ The issue fee and publication fee, if applicable, has not been received.

3. ☐ Applicant's failure to timely file corrected drawings as required by, and within the three-month period set in, the Notice of Allowability (PTO-37).
 - (a) ☐ Proposed corrected drawings were received on _____ (with a Certificate of Mailing or Transmission dated _____), which is after the expiration of the period for reply.
 - (b) ☐ No corrected drawings have been received.

4. ☐ The letter of express abandonment which is signed by the attorney or agent of record or other party authorized under 37 CFR 1.33(b). See 37 CFR 1.138(b).

5. ☐ The letter of express abandonment which is signed by an attorney or agent (acting in a representative capacity under 37 CFR 1.34) upon the filing of a continuing application.

6. ☐ The decision by the Board of Patent Appeals and Interference rendered on _____ and because the period for seeking court review of the decision has expired and there are no allowed claims.

7. ☐ The reason(s) below:

/JACK W KEITH/
Supervisory Patent Examiner, Art Unit 3646

/S. P. B./
Examiner, Art Unit 3646

Petitions to revive under 37 CFR 1.137, or requests to withdraw the holding of abandonment under 37 CFR 1.181, should be promptly filed to minimize any negative effects on patent term.



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| APPLICATION NUMBER | FILING OR 371(C) DATE | FIRST NAMED APPLICANT | ATTY. DOCKET NO./TITLE |
|--------------------|-----------------------|-----------------------|------------------------|
| 13/591,162 | 08/21/2012 | Christopher H. Cooper | 1112.0001-05000 |

CONFIRMATION NO. 1832

68540
O'BRIEN JONES, PLLC
1951 Kidwell Drive
Suite 740
Tysons Corner, VA 22182

PUBLICATION NOTICE



OC000000064322299

Title:METHODS OF GENERATING ENERGETIC PARTICLES USING NANOTUBES AND ARTICLES THEREOF

Publication No.US-2013-0266106-A1

Publication Date:10/10/2013

NOTICE OF PUBLICATION OF APPLICATION

The above-identified application will be electronically published as a patent application publication pursuant to 37 CFR 1.211, et seq. The patent application publication number and publication date are set forth above.

The publication may be accessed through the USPTO's publically available Searchable Databases via the Internet at www.uspto.gov. The direct link to access the publication is currently <http://www.uspto.gov/patft/>.

The publication process established by the Office does not provide for mailing a copy of the publication to applicant. A copy of the publication may be obtained from the Office upon payment of the appropriate fee set forth in 37 CFR 1.19(a)(1). Orders for copies of patent application publications are handled by the USPTO's Office of Public Records. The Office of Public Records can be reached by telephone at (703) 308-9726 or (800) 972-6382, by facsimile at (703) 305-8759, by mail addressed to the United States Patent and Trademark Office, Office of Public Records, Alexandria, VA 22313-1450 or via the Internet.

In addition, information on the status of the application, including the mailing date of Office actions and the dates of receipt of correspondence filed in the Office, may also be accessed via the Internet through the Patent Electronic Business Center at www.uspto.gov using the public side of the Patent Application Information and Retrieval (PAIR) system. The direct link to access this status information is currently <http://pair.uspto.gov/>. Prior to publication, such status information is confidential and may only be obtained by applicant using the private side of PAIR.

Further assistance in electronically accessing the publication, or about PAIR, is available by calling the Patent Electronic Business Center at 1-866-217-9197.

Office of Data Management, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101



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| APPLICATION NO. | FILING DATE | FIRST NAMED INVENTOR | ATTORNEY DOCKET NO. | CONFIRMATION NO. |
|-----------------------------------------------------------------------------------|-------------|-----------------------|---------------------------------|-----------------------------|
| 13/591,162 | 08/21/2012 | Christopher H. Cooper | 1112.0001-05000 | 1832 |
| 68540 | 7590 | 07/12/2013 | | |
| O'BRIEN JONES, PLLC 1951 Kidwell Drive Suite 740 Tysons Corner, VA 22182 | | | EXAMINER BURKE, SEAN P | |
| | | | ART UNIT 3646 | PAPER NUMBER |
| | | | NOTIFICATION DATE 07/12/2013 | DELIVERY MODE ELECTRONIC |

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

Notice of the Office communication was sent electronically on above-indicated "Notification Date" to the following e-mail address(es):

docketing@obrienjones.com

Office Action SummaryApplication No.
13/591,162Applicant(s)
COOPER ET AL.Examiner
SEAN P. BURKEArt Unit
3646AIA (First Inventor to File)
Status
No

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTH(S) OR THIRTY (30) DAYS, WHICHEVER IS LONGER, FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133). Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

- 1) ☒ Responsive to communication(s) filed on 2 May 2013.
☐ A declaration(s)/affidavit(s) under **37 CFR 1.130(b)** was/were filed on _____.
- 2a) ☐ This action is **FINAL**. 2b) ☒ This action is non-final.
- 3) ☐ An election was made by the applicant in response to a restriction requirement set forth during the interview on _____; the restriction requirement and election have been incorporated into this action.
- 4) ☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims

- 5) ☒ Claim(s) 1-24 is/are pending in the application.
5a) Of the above claim(s) _____ is/are withdrawn from consideration.
- 6) ☐ Claim(s) _____ is/are allowed.
- 7) ☒ Claim(s) 1-24 is/are rejected.
- 8) ☐ Claim(s) _____ is/are objected to.
- 9) ☐ Claim(s) _____ are subject to restriction and/or election requirement.

* If any claims have been determined allowable, you may be eligible to benefit from the **Patent Prosecution Highway** program at a participating intellectual property office for the corresponding application. For more information, please see http://www.uspto.gov/patents/init_events/pph/index.jsp or send an inquiry to PPHfeedback@uspto.gov.

Application Papers

- 10) ☒ The specification is objected to by the Examiner.
- 11) ☒ The drawing(s) filed on 21 August 2012 is/are: a) ☒ accepted or b) ☐ objected to by the Examiner.
Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).
Replacement drawing sheet(s) including the correction is required if the drawing(s) is objected to. See 37 CFR 1.121(d).

Priority under 35 U.S.C. § 119

- 12) ☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

Certified copies:

- a) ☐ All b) ☐ Some * c) ☐ None of the:
1. ☐ Certified copies of the priority documents have been received.
 2. ☐ Certified copies of the priority documents have been received in Application No. _____.
 3. ☐ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

* See the attached detailed Office action for a list of the certified copies not received.

Attachment(s)

- 1) ☐ Notice of References Cited (PTO-892)
- 2) ☒ Information Disclosure Statement(s) (PTO/SB/08)
Paper No(s)/Mail Date 5/2/2013
- 3) ☐ Interview Summary (PTO-413)
Paper No(s)/Mail Date. _____.
- 4) ☒ Other: Detailed Action.

DETAILED ACTION

Specification

1. The following is a quotation of 35 U.S.C. 112(a):
(a) IN GENERAL.—The specification shall contain a written description of the invention, and of the manner and process of making and using it, in such full, clear, concise, and exact terms as to enable any person skilled in the art to which it pertains, or with which it is most nearly connected, to make and use the same, and shall set forth the best mode contemplated by the inventor or joint inventor of carrying out the invention.

The following is a quotation of 35 U.S.C. 112 (pre-AIA), first paragraph:
The specification shall contain a written description of the invention, and of the manner and process of making and using it, in such full, clear, concise, and exact terms as to enable any person skilled in the art to which it pertains, or with which it is most nearly connected, to make and use the same and shall set forth the best mode contemplated by the inventor of carrying out his invention.

2. The specification is objected to under 35 U.S.C. 112, first paragraph as failing to provide an adequate written description of the invention and as failing to adequately teach how to make and/or used the invention, i.e. failing to provide an enabling disclosure. There are many factors recognized by the MPEP that are to be considered when determining whether there is insufficient evidence to support a determination that a disclosure satisfies the enablement requirement, including the nature of the invention, the level of predictability in the art and the existence of working examples. See MPEP 2164.01 (a). The examiner has the initial burden of challenging an asserted utility. Once the examiner has provided evidence showing that one of ordinary skill in the art would reasonably doubt the asserted utility of the invention, the burden shifts to the applicant to provide rebuttal evidence. See MPEP 2164.07(8).
3. Invention of the present application lacks utility because it is inoperable. Such inoperability is referred to by the Applicant in the specification: "[002] Disclosed herein are methods of generating energetic particles, by contacting nanotubes with hydrogen

isotopes in the presence of activation energy, such as thermal, electromagnetic, or the kinetic energy of particles" and "[004] Devices powered with nanotube based nuclear power systems may substantially change the current state of power distribution. For example, nanotube based nuclear power systems may reduce, if not eliminate, the need for power distribution networks; chemical batteries; energy scavenger devices such as solar cells, windmills, hydroelectric power stations; internal combustion, chemical rocket, or turbine engines; as well as all other forms of chemical combustion for the production of power" (i. e. with release of the nuclear energy above a spend one for activation) relies on phenomena (Also disclosed are methods of (nuclear) transmuting matter by exposing such matter to the energetic particles produced according to the disclosed method) that are not proven and/or are contrary to a modern nuclear physics, to the current understanding of physics and because, even if it were possible to practice the invention, the applicant has not described the method used to implement it in sufficient detail to enable a skilled artisan to make and use it without undue experimentation.

4. It may be possible to generate energetic particles by contacting nanotubes with hydrogen isotopes in the presence of very high power density activation energy, such as thermal, electromagnetic, or the kinetic energy of particles. It may also be possible to transmuting matter by exposing such matter to the energetic particles produced according to the disclosed method, but the energy necessary for the activation of hydrogen isotopes is much higher than released from said nuclear transmutation.

5. Hydrogen isotope localization by nanotubes (and electron shielding) is similar to hydrogen isotopes localization in other molecules and cannot increase probability of nuclear transmutation (nuclear fusion) significantly as demonstrated in recent experiments (F. Raiola et al, "Electron shielding in d(d,p)t for deuterated metals and the periodic table", Physics Letters B, V. 547 (3-4), pp.193-199, 2002). Parameters of said "activation" are disclosed in many books related to nuclear fusion for example in Knief, "Nuclear engineering", Hemisphere Publishing Corporation, 1992, pp. 636,642. For net energy production in the D-T reaction, the D-T compound must be heated to 10 keV (approximately a hundred million degrees Celsius), to say nothing of the remaining Lawson Criteria (page 641, lines 11+). Electron shielding decreases the threshold energy for d-d fusion marginally and does not permit net energy production with a low activation energy.

6. Until now net energy production from solid hydrogen isotopes transmutation were activated only by a nuclear explosion in a hydrogen bomb-style fusion explosion.

7. Applicant's statement of asserted utility that "Devices powered with nanotube based nuclear power systems may substantially change the current state of power distribution. For example, nanotube based nuclear power systems may reduce, if not eliminate, the need for power distribution networks; chemical batteries; energy scavenger devices such as solar cells, windmills, hydroelectric power stations; internal combustion, chemical rocket, or turbine engines; as well as all other forms of chemical combustion for the production of power" cannot operate as disclosed because a claimed "contacting nanotubes with hydrogen isotopes" cannot enhance an energy efficiency of

nuclear transmutation significantly up to possible release of net nuclear energy (as discussed above).

8. The nature of the invention rests on certain basic concepts, including the following:

a. [005] Accordingly, there is disclosed a method of generating energetic particles, which comprises contacting nanotubes with hydrogen isotopes and applying activation energy to the nanotubes. In one embodiment, the hydrogen isotopes comprises protium, deuterium, tritium, and combinations thereof.

b. [006] There is also disclosed a method of transmuting matter that comprises contacting nanotubes with a source of hydrogen isotopes, applying activation energy to the nanotubes, producing energetic particles, and contacting the matter to be transmuted with the energetic particles. As used herein, transmutable matter is matter that is transformed from one element or isotope to another element or isotope).

9. The applicant claims that the neutron detection was observed from nanotubes contacting heavy water during rotation and illumination by UV filtered halogen light, however, short current pulsing through nanotubes and heavy water is not credible.

10. There is no credible record to indicate that the "Examples" (pp. 12+) are based on either rigorous or credible experimental evidence. Furthermore, the "examples" directly contradict accepted science. In experiments involving high sensitive detectors, such as ^3He neutron detectors or Germanium detectors for registration of very weak signals and fast pulsing devices for lamp and current pulsing, there is a very high

probability for registration of correlated signal through a "cross talk", a transmission of fast pulsed electromagnetic signal directly next to the detector entrance. There is no credible information related to protection of the detection system from this type of "cross talk".

11. In the presence of deuterium, as in disclosed "examples", it is possible to have a limited number of neutrons produced through generation of high voltage by high frequency-pulse transformation or by electrostatic induction and high voltage breakdown with acceleration of some deuterons above threshold energy for neutron generation. However, a small amount of neutron generation is not enough for net energy production. For net energy production by d-d reaction it is necessary to generate at least 10^{12} neutrons per second for every Watt of generated power.

12. Contacting nanotubes with hydrogen isotopes in the presence of activation energy, such as thermal, electromagnetic, or the kinetic energy of particles have place in nanotubes production by discharges in hydrocarbon atmosphere, but no neutron emission or any nuclear transformations were credibly observed in thousands of such experiments around the world (see review of Melechko, cited before).

13. Below is presented a conclusions of DOE 2004 Report of the Review of Low Energy Nuclear Reactions ("cold fusion"):

14. While significant progress has been made in the sophistication of calorimeters since the review of this subject in 1989, the conclusions reached by the reviewers today are similar to those found in the 1989 review (Page 5, lines 15+). It is no any credible

evidence of net energy generation by low energy activated fusion reaction with any catalyst.

15. As stated in MPEP § 2164.03, the amount of guidance or direction needed to enable the invention is inversely related to the amount of knowledge in the state of the art as well as the predictability in the art. *In re Fisher*, 427 F2d 833,839, 166 USPQ 18, 24 (CCPA 1970). The art of the present invention (transmuting of matter and energy generation by contacting of said matter with a nanotube structure and exposing said nanotube structure to activation energy) is so new that it cannot be considered to have a body of knowledge associated with it, much less predictability of results (see *Chiton Corp. v. Genentech Inc.*, 363 F.3d 1247, 1254, 70 USPQ 2d 1321, 1326 (Fed. Cir. 2004)). Applicant has only provided data that is based upon questionable science, and so that data is also questionable until such time that applicant rigorously proves that the applied concepts are plausible and the data statistically sound. Since Applicant has not established the operability of the presently claimed invention as discussed, the invention lacks utility. Given the state of the art as discussed herein, it would be unreasonable to expect one skilled in the art to be able to make and use the claimed invention without undue experimentation.

16. It is well established that where, as here, the utility of the claimed invention is based upon allegations that border on the incredible or allegations that would not be readily accepted by a substantial portion of the scientific community, sufficient substantiating evidence of operability must be submitted by applicant. *In re Houghton*, 167 USPQ 687 (CCPA 1970); *In re Ferens*, 163 USPQ 609 (CCPA 1969); *Puharich v.*

Brenner, 162 USPQ 136 (CA DC 1969); *In re Pottier*, 152 USPQ 407 (CCPA 1967); *In re Ruskin*, 148 USPQ 221 (CCPA 1966); *In re Citron*, 139 USPQ 516 (CCPA 1963); and *In re Novak*, 134 USPQ 335 (CCPA 1962).

17. Simply stating that the concepts the inventor espouses are correct is not sufficient substantiating evidence. Sufficient substantiating evidence may be based on widely accepted scientific concepts (e.g., quantum nuclear physics), a working model, or a supporting opinion in a widely respected and peer-reviewed publication (existing credible publications do not support optimistic Applicant's assumptions).

18. It is thus considered that the examiner has set forth a reasonable and sufficient basis for challenging the adequacy of the disclosure. The statute requires the applicant itself to inform, not to direct others to find out for themselves; *In re Gardner et al*, 166 USPQ 138, *In re Scarbrough*, 182 USPQ 298. Note that the disclosure must enable a person skilled in the art to practice the invention without having to design structure not shown to be readily available in the art. *In re Hirsch*, 131 USPQ 198.

19. Given the state of the art as discussed herein, it is unreasonable to expect one skilled in the art to be able to make and use the claimed invention without undue experimentation.

20. The claimed invention as a whole must be useful and accomplish a practical application. That is, it must produce a "useful, concrete and tangible result." *State Street*, 149 F.3d at 1373-74, 47 USPQ2d at 1601-02. The purpose of this requirement to limit patent protection to inventions that possess a certain level of "real world" value, as opposed to subject matter that represents nothing more than an idea or concept, or

is simply a starting point for future investigation or research (*Brenner v. Manson*, 383 U.S. 519, 528-36, 148 USPQ 689, 693-96 (1966)); *In re Fisher*, 421 F3d 1365, 76 USPQ2d 1225 (Fed. Cir. 2005); *In re Ziegler*, 992 F2d 1197, 1200-03, 26 USPQ2d 1600, 1603-06 (Fed. Cir. 1993)).

MPEP 2164.01 (a) Undue Experimentation Factors

21. There are many factors to be considered when determining whether there is sufficient evidence to support a determination that a disclosure does not satisfy the enablement requirement and whether any necessary experimentation is "undue." These factors include, but are not limited to:

- a. The breadth of the claims - The invention alleges to solve the "fusion energy generation and nuclear transmutation problem, by contact of nanotubes with hydrogen isotopes." The enhancement of nuclear fusion energy generation and nuclear transmutation by contact of nanotubes with hydrogen isotopes is not established in modern nuclear science and contradicts some of the basic principle of nuclear physics.
- b. The nature of the invention - The invention is a method for nuclear transmutation and energy production through "contacting of nanotubes with hydrogen isotopes and exposure to activation energy"; thus the nature of the invention as disclosed involves very drastic change of hypotheses in the nuclear physics;
- c. The state of the prior art- The effects claimed by the Applicant were not observed in many experiments with much, much higher scale. (Hydrogen

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isotopes localization produced by contact with nanotubes is hundred thousand times larger than hydrogen isotope size and cannot enhance nuclear transmutation probability);

d. The level of one of ordinary skill - There is no documented evidence in support of nuclear transmutation enhancement by contact of nanotubes with hydrogen isotopes;

e. The level of predictability in the art – The alleged nuclear transmutation and net energy generation by contacting nanotubes with hydrogen isotopes as claimed is likely impossible.

f. The amount of direction provided by the inventor – The amount of direction supplied is wholly insufficient because inventor has presented assumptions and speculations related to nuclear transmutation and neutron generation which are not confirmed in independent experiments.

g. The existence of working examples - The data provided dealing with neutron detection during activation of nanotubes contacting with hydrogen isotopes (D₂O) is incredible and does not have independent confirmation.

h. The quantity of experimentation needed to make or use the invention based on the content of the disclosure – The obvious need for undue experimentation and would likely have negative results.

Claim Rejections - 35 USC § 112

22. The following is a quotation of 35 U.S.C. 112(a):

(a) IN GENERAL.—The specification shall contain a written description of the invention, and of the manner and process of making and using it, in such full, clear, concise, and exact terms as to enable any person skilled in the art to which it pertains, or with which it is most nearly

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connected, to make and use the same, and shall set forth the best mode contemplated by the inventor or joint inventor of carrying out the invention.

The following is a quotation of 35 U.S.C. 112 (pre-AIA), first paragraph:

The specification shall contain a written description of the invention, and of the manner and process of making and using it, in such full, clear, concise, and exact terms as to enable any person skilled in the art to which it pertains, or with which it is most nearly connected, to make and use the same and shall set forth the best mode contemplated by the inventor of carrying out his invention.

23. Claims 1-24 are rejected under 35 U.S.C. 112(a) or 35 U.S.C. 112 (pre-AIA), first paragraph, as failing to comply with the enablement requirement. The claim(s) contains subject matter which was not described in the specification in such a way as to enable one skilled in the art to which it pertains, or with which it is most nearly connected, to make and/or use the invention. Specifically, the invention is inoperable and therefore cannot be adequately enabled by the specification.

24. The following is a quotation of 35 U.S.C. 112(b):

(b) CONCLUSION.—The specification shall conclude with one or more claims particularly pointing out and distinctly claiming the subject matter which the inventor or a joint inventor regards as the invention.

The following is a quotation of 35 U.S.C. 112 (pre-AIA), second paragraph:

The specification shall conclude with one or more claims particularly pointing out and distinctly claiming the subject matter which the applicant regards as his invention.

25. Claim 1-24 are rejected under 35 U.S.C. 112(b) or 35 U.S.C. 112 (pre-AIA), second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which the inventor or a joint inventor, or for pre-AIA the applicant regards as the invention. Specifically, it is not clear how one of ordinary skill in the art would produce a functioning model of the alleged device from the specification provided.

Claim Rejections - 35 USC § 101

26. 35 U.S.C. 101 reads as follows:

Whoever invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent therefor, subject to the conditions and requirements of this title.

27. Claims 1-24 are rejected under 35 U.S.C. 101 because the disclosed invention is inoperative and therefore lacks utility. Specifically, Applicant's invention is directed to an allegedly low energy nuclear reaction, a statutorily inoperable invention. *In re Swartz*, 232 F.3d 862 (2000). The rationale for this rejection is the same as for the objection to the specification above.

Claim Rejections - 35 USC § 102

28. The following is a quotation of the appropriate paragraphs of pre-AIA 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

A person shall be entitled to a patent unless –
(b) the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of application for patent in the United States.

29. Claims 1-23 are rejected under pre-AIA 35 U.S.C. 102(b) as being anticipated by Melechko, et al., "Vertically aligned carbon nanofibers and related structures: Controlled synthesis and direct assemble."

30. It is noted that while the method as claimed is anticipated by the prior art, the utility as asserted in the specification is not enabled in or by the reference.

31. Regarding Claim 1, Melechko discloses: a method of generating energetic particles (the energetic electrons, protons as component of decomposed and ionized molecules; page 12, column 2, lines 35+), said method comprising contacting nanotubes (aligned carbon nanotubes; page 12, column 2, lines 27) with hydrogen isotopes (mixture of methane and hydrogen isotopes used as working gas), and applying activation energy (corona discharge plasma; page 12, column 2, lines 25+) to

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said nanotubes (during nanotube formation by chemical vapor deposition and plasma enhanced chemical and physical vapor deposition from mixture of hydrocarbons such as benzene and hydrogen, nanotubes are contacted with hydrogen isotopes and activation energy is applied to nanotube such as thermal energy, radiations, particles bombardment. Sputtered particles and radiations are generated from these processes.

FIG. 11, 12, page 8 column 2, lines 18+).

32. On claim 2, Melechko additionally teaches: said hydrogen isotopes comprise protium, deuterium, tritium, and combinations thereof (hydrogen used for deposition comprises protium and deuterium, tritium can be generated during bombardment of high energy particles and can presents as impurity, (page 8, column 2, lines 24+).

33. On claim 3, Melechko additionally teaches: said hydrogen isotopes are provided from a source that is in a solid, liquid, gas, plasma, or supercritical phase (FIG. 12, page 9, column 1, lines 1 +).

34. On claim 4: Melechko additionally teaches: said hydrogen isotopes are provided from a source that are bound in a molecular structure (NH_3 gas, benzene, FIG. 12, page 9, column 1, lines 1 +).

35. On claim 5: Melechko additionally teaches: hydrogen isotopes are provided via D_2O (water vapor adsorbed on the nanotube surface includes D_2O).

36. On claim 6: Melechko additionally teaches: said activation energy comprises thermal, electromagnetic, or the kinetic energy of a particle (deposition activated by heating and discharge generating by DC or RF current, (FIG. 12, page 9, column 1, lines 1 +; corona discharge plasma; page 12, column 2, lines 25+).

37. On claim 7: Melechko additionally teaches: said electromagnetic energy comprises one or more sources chosen from x-rays, optical photons, X-rays, microwave radiation, infrared radiation, ultraviolet radiation, phonons, radiation in the frequencies ranging from gigahertz to terahertz, or combinations thereof (table I, table II, FIG. 12, page 8, column 2, lines 18+).

38. On claim 8: Melechko teaches: said particle containing kinetic energy is chosen from neutrons, protons, electrons, beta radiation, alpha radiation, and combinations thereof (the energetic electrons, protons as component of decomposed and ionized molecules; page 12, column 2, lines 35+).

39. On claim 9: Melechko additionally teaches: said energetic particles comprise neutrons, protons, electrons, beta radiation, alpha radiation, and combinations thereof (the energetic electrons, protons as component of decomposed and ionized molecules; page 12, column 2, lines 35+).

40. On claim 10: Melechko additionally teaches: said nanotubes comprise carbon nanotubes (page 22, column 2, lines 6+; aligned carbon nanotubes; page 12, column 2, lines 27).

41. On claim 11: Melechko additionally teaches: said nanotube is a multiwalled carbon nanotube (FIG. 2, 7, 8, Table II; aligned carbon nanotubes; page 12, column 2, lines 27).

42. On claim 12: Melechko additionally teaches: said nanotube is a multiwalled carbon nanotube has a length ranging from 500 μ m to 10cm (all possible dimensions of nanotube and nanofibers are disclosed).

43. On claim 13: Melechko additionally teaches: said nanotube is a multi-walled carbon nanotube having a length ranging from 2mm to 10mm (all possible dimensions of nanotube and nanofibers are disclosed).

44. On claim 14: Melechko additionally teaches: said hydrogen isotopes are located within the interior of a nanotube, the space between the walls of a multiwalled nanotube, inside at least one loop formed by one or more nanotubes, or combinations thereof (FIG. 1, 2, 7, 8, hydrogen isotopes have high affinity to carbon and have high ability for adsorption).

45. On claim 15: Melechko additionally teaches: forming a bundle of carbon nanotubes and providing activation energy in the form of electrical energy, to the bundle (FIG. 31).

46. On claim 16: Melechko additionally teaches: said electrical energy is in the form of an electrical pulse (Table I and Table II).

47. On claim 17: Melechko additionally teaches: said nanotubes are aligned end to end, parallel, or in any combination thereof (FIG. 5, FIG. 10).

48. On claim 18: Melechko additionally teaches: said nanotube structure has an inside diameter ranging up to 100nm (FIG. 2).

49. On claim 19: Melechko additionally teaches: said nanotube is comprised of insulating, metallic, or semiconducting materials and combinations of such materials (page 24, column 2, lines 15+).

50. On claim 20: Melechko additionally teaches: said nanotubes consist essentially of carbon and its allotropes (page 12, column 2, lines 45+, Table I and table II).

51. On claim 21: Melechko additionally teaches: at least partially coating or doping least one atomic or molecular layer of an inorganic material prior to applying said activation energy (inherently, during nanotubes formation in gas discharge a sputtered material deposited to the nanotubes surface).

52. On claim 22: Melechko additionally teaches: said activation energy comprises environmental background radiation (inherent).

53. On claim 23: Melechko additionally teaches: said environmental background radiation comprises cosmic rays (inherent).

54. Claim 24 is rejected under 35 U.S.C. 102(e) as being anticipated by US Patent Application Publication No. 2008/0251735 (herein after "Putterman et al.").

55. Regarding Claim 24, Putterman et al. teaches a method of transmuting matter 26, said method comprising contacting nanotubes 24 with a source of hydrogen isotopes (paragraph 0035), applying activation energy to said nanotubes, producing energetic particles (paragraphs 0016 and 0024), and contacting the matter 26 to be transmuted with said energetic particles (figure 1).

56. Claims 1-11, 14-20, and 22-23 are rejected under 35 U.S.C. 102(b) as being anticipated by Observation of Water Confined in Nanometer Channels of Closed Carbon Nanotubes (herein after "Naguib et al.").

57. Regarding Claim 1, Naguib et al. teaches a method of generating energetic particles, said method comprising contacting nanotubes with hydrogen isotopes, and applying activation energy to said nanotubes (page 2237; column 1, lines 12-13; page 2238, column 1, lines 19-21; page 2240, column 2, lines 43-49).

58. Regarding Claim 2, Naguib et al. teaches a method wherein said hydrogen isotopes comprise protium, deuterium, tritium, and combinations thereof (page 2238; column 1, lines 19-21).

59. Regarding Claim 3, Naguib et al. teaches a method wherein said hydrogen isotopes are provided from a source that is in a solid, liquid, gas, plasma, or supercritical phase (page 2238; column 1, lines 19-21).

60. Regarding Claim 4, Naguib et al. teaches a method wherein said hydrogen isotopes are provided from a source that are bound in a molecular structure (page 2238; column 1, lines 19-21).

61. Regarding Claim 5, Naguib et al. teaches a method wherein hydrogen isotopes are provided via O₂ (page 2238; column 1, lines 19-21).

62. Regarding Claim 6, Naguib et al. teaches a method wherein said activation energy comprises thermal, electromagnetic, or the kinetic energy of a particle (page 2238; column 2, lines 1-9 and page 2240; column 2, lines 43-49).

63. Regarding Claim 7, Naguib et al. teaches a method wherein said electromagnetic energy comprises one or more sources chosen from x-rays, optical photons, γ -rays, microwave radiation, infrared radiation, ultraviolet radiation, phonons, radiation in the frequencies ranging from gigahertz to terahertz, or combinations thereof (page 2237; column 1, lines 12-13 and page 2238; column 2, lines 1-9).

64. Regarding Claim 8, Naguib et al. teaches a method wherein said particle containing kinetic energy is chosen from neutrons, protons, electrons, beta radiation,

alpha radiation, mesons, pions, hadrons, leptons, baryons, and combinations thereof (page 2237; column 1, lines 12-13 and page 2238; column 2, lines 1-9).

65. Regarding Claim 9, Naguib et al. teaches a method wherein said energetic particles comprise neutrons, protons, electrons, beta radiation, alpha radiation, mesons, pions, hadrons, leptons, baryons, and combinations thereof (page 2237; column 1, lines 12-13 and page 2238; column 2, lines 1-9).

66. Regarding Claim 10, Naguib et al. teaches a method wherein said nanotubes comprise carbon nanotubes (abstract, line 1).

67. Regarding Claim 11, Naguib et al. teaches a method wherein said nanotube is a multi-walled carbon nanotube (abstract, line 1).

68. Regarding Claim 14, Naguib et al. teaches a method wherein said hydrogen isotopes are located within the interior of a nanotube, the space between the walls of a multi-walled nanotube, inside at least one loop formed by one or more nanotubes, or combinations thereof (page 2238; column 1, lines 19-21).

69. Regarding Claim 15, Naguib et al. teaches a method further comprising forming a bundle of carbon nanotubes and providing activation energy in the form of electrical energy, to the bundle (page 2239; column 2, lines 12-14).

70. Regarding Claim 16, Naguib et al. teaches a method wherein said electrical energy is in the form of an electrical pulse (page 2238; column 2, lines 6-9).

71. Regarding Claim 17, Naguib et al. teaches a method wherein said nanotubes are aligned end to end, parallel, or in any combination thereof (page 2239; column 2, lines 12-14).

72. Regarding Claim 18, Naguib et al. teaches a method wherein said nanotube structure has an inside diameter ranging up to 100nm (abstract, line 1; page 2237; column 1, line 15).
73. Regarding Claim 19, Naguib et al. teaches a method wherein the said nanotube is comprised of insulating, metallic, or semiconducting materials and combinations of such materials (abstract, line 1).
74. Regarding Claim 20, Naguib et al. teaches a method wherein said nanotubes consist essentially of carbon and its allotropes (abstract, line 1).
75. Regarding Claim 22, Naguib et al. teaches a method wherein said activation energy comprises environmental background radiation (page 2238; column 2, lines 6-9).
76. Regarding Claim 23, Naguib et al. teaches a method wherein said environmental background radiation comprises cosmic rays (page 2238; column 2, lines 6-9).

Claim Rejections - 35 USC § 103

77. The following is a quotation of pre-AIA 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

(a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negated by the manner in which the invention was made.

78. The factual inquiries set forth in *Graham v. John Deere Co.*, 383 U.S. 1, 148 USPQ 459 (1966), that are applied for establishing a background for determining obviousness under pre-AIA 35 U.S.C. 103(a) are summarized as follows:

1. Determining the scope and contents of the prior art.
2. Ascertaining the differences between the prior art and the claims at issue.

3. Resolving the level of ordinary skill in the pertinent art.

4. Considering objective evidence present in the application indicating obviousness or nonobviousness.

79. This application currently names joint inventors. In considering patentability of the claims under pre-AIA 35 U.S.C. 103(a), the examiner presumes that the subject matter of the various claims was commonly owned at the time any inventions covered therein were made absent any evidence to the contrary. Applicant is advised of the obligation under 37 CFR 1.56 to point out the inventor and invention dates of each claim that was not commonly owned at the time a later invention was made in order for the examiner to consider the applicability of pre-AIA 35 U.S.C. 103(c) and potential pre-AIA 35 U.S.C. 102(e), (f) or (g) prior art under pre-AIA 35 U.S.C. 103(a).

80. Claims 12 and 13 are rejected under pre-AIA 35 U.S.C. 103(a) as being unpatentable over Naguib et al., "Observation of Water Confined in Nanometer Channels of Closed Carbon Nanotubes."

81. Regarding Claim 12, Naguib et al. teaches a method wherein said nanotube is a multi-walled carbon nanotube (abstract, line 1), but fails to specifically teach that said nanotube has a length ranging from 500um to 10cm. However, one of ordinary skill in the art is expected to routinely experiment with the parameters, especially when the specifics are not disclosed, so as to ascertain the optimum or workable ranges for a particular use. Accordingly, it would have been obvious through routine experimentation and optimization, for one of ordinary skill in the art to construct the nanotube to have a length ranging from 500um to 10cm.

82. Regarding Claim 13, Naguib et al. teaches a method wherein said nanotube is a multi-walled carbon nanotube (abstract, line 1), but fails to specifically teach that said nanotube has a length ranging from 2mm to 10mm. However, one of ordinary skill in the art is expected to routinely experiment with the parameters, especially when the specifics are not disclosed, so as to ascertain the optimum or workable ranges for a particular use. Accordingly, it would have been obvious through routine experimentation and optimization, for one of ordinary skill in the art to construct the nanotube to have a length ranging from 2mm to 10mm.

83. Claim 21 rejected under pre-AIA 35 U.S.C. 103(a) as being unpatentable over Naguib in view of Ziden et al, "Doped Carbon Nanotubes for Hydrogen Storage."

84. Regarding Claim 21, Naguib et al. teaches a method, but fails to teach the step of at least partially coating or doping least one atomic or molecular layer of an inorganic material prior to applying said activation energy.

85. Ziden et al. teaches at least partially coating or doping least one atomic or molecular layer of an inorganic material prior to applying said activation energy (figure 3; page 3, column 1, lines 6-8).

86. A motivation for doping the carbon nanotube with an inorganic material prior to applying an activation energy is to avoid inconsistency in measurements, allow for a weak covalent bond, and tune the nanotube for hydrogen sorption occurring at a desired temperature and pressure (Ziden et al.; page 2, column 1, paragraph 2). Thus, it

would have been obvious to one of ordinary skill in the art at the time of the invention to dope the nanotube as described above.

Conclusion

87. The prior art made of record and not relied upon is considered pertinent to applicant's disclosure.

Any inquiry concerning this communication or earlier communications from the examiner should be directed to SEAN P. BURKE whose telephone number is (571)270-5493. The examiner can normally be reached on Monday-Friday, 8:30 AM to 5:00 PM..

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Jack Keith can be reached on (571) 262-6878. The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see <http://pair-direct.uspto.gov>. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free). If you would like assistance from a USPTO Customer Service Representative or access to the automated information system, call 800-786-9199 (IN USA OR CANADA) or 571-272-1000.

Application/Control Number: 13/591,162

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Art Unit: 3646

/S. P. B./

Examiner, Art Unit 3646

/JACK W KEITH/

Supervisory Patent Examiner, Art Unit 3646

| | | |
|------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|---------------------------------------------------------------------|
| <i>Index of Claims</i>  | Application/Control No. 13591162 | Applicant(s)/Patent Under Reexamination COOPER ET AL. |
| | Examiner SEAN P BURKE | Art Unit 3646 |

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|---|-----------------|---|-------------------|---|---------------------|---|-----------------|
| ✓ | Rejected | - | Cancelled | N | Non-Elected | A | Appeal |
| = | Allowed | ÷ | Restricted | I | Interference | O | Objected |

| <input type="checkbox"/> Claims renumbered in the same order as presented by applicant | | <input type="checkbox"/> CPA | | <input type="checkbox"/> T.D. | | <input type="checkbox"/> R.1.47 | | | |
|----------------------------------------------------------------------------------------|----------|------------------------------|--|-------------------------------|--|---------------------------------|--|--|--|
| CLAIM | | DATE | | | | | | | |
| Final | Original | 07/02/2013 | | | | | | | |
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Doc code: IDS

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PTO/SB/08a (01-10)

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|-----------------------------------------------------------------------------------------------------|------------------------|-----------------------|------------|--|
| INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99) | Application Number | | 13591162 | |
| | Filing Date | | 2012-08-21 | |
| | First Named Inventor | Christopher H. COOPER | | |
| | Art Unit | 1736 | | |
| | Examiner Name | TBD | | |
| | Attorney Docket Number | 1112.0001-05000 | | |

U.S.PATENTS

| Examiner Initial* | Cite No | Patent Number | Kind Code ¹ | Issue Date | Name of Patentee or Applicant of cited Document | Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear |
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|-------------------|---------|--------------------|------------------------|------------------|-------------------------------------------------|------------------------------------------------------------------------|
| | 1 | 20080251735 | A1 | 2008-10-16 | Putterman et al. | |
| | 2 | 20050238565 | A1 | 2005-10-27 | Sullivan | |
| | 3 | 20060072697 | A1 | 2006-04-06 | Proctor | |
| | 4 | 20080123793 | A1 | 2008-05-29 | Loan et al. | |

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**INFORMATION DISCLOSURE
STATEMENT BY APPLICANT**
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| Examiner Name | TBD |
| Attorney Docket Number | 1112.0001-05000 |

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|---|---------------|----|----|------------|-------------|--|--------------------------|
| 1 | WO2005/001845 | WO | A2 | 2005-01-06 | Rosen | | <input type="checkbox"/> |
| 2 | WO2005/065095 | WO | A2 | 2005-07-21 | Gaidis | | <input type="checkbox"/> |
| 3 | EP1551032 | EP | A1 | 2005-07-06 | Arata | | <input type="checkbox"/> |
| 4 | WO99/65821 | WO | A1 | 1999-12-23 | Ren et al. | | <input type="checkbox"/> |
| 5 | WO90/13129 | WO | A2 | 1990-11-01 | Hagelstein | | <input type="checkbox"/> |
| 6 | WO2007/102860 | WO | A2 | 2007-09-13 | Loan et al. | | <input type="checkbox"/> |

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|--------------------|---------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|
| | 1 | International Search Report for related International Application PCT/US2006/045753, dated November 6, 2007. | <input type="checkbox"/> |
| | 2 | International Search Report and Written Opinion for related International Application PCT/US2011/066992, dated April 5, 2012. | <input type="checkbox"/> |
| | 3 | MELECHKO et al., "Vertically aligned carbon nanofibers and related structures: Controlled synthesis and directed assembly," Journal of Applied Physics, No. 97, 2005, pp. 1-39. | <input type="checkbox"/> |

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| Attorney Docket Number | 1112.0001-05000 |

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|----|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|
| 4 | NAGUIB et al., "Observation of Water Confined in Nanometer Channels of Closed Carbon Nanotubes," Oct. 14, 2004, Nano Letters, Vol. 4, No. 11, pp. 2237-43. | <input type="checkbox"/> |
| 5 | ZIDAN et al., "Doped Carbon Nanotubes for Hydrogen Storage," 2003, Hydrogen, Fuel Cells, and Infrastructure Technologies, pp. 1-4. | <input type="checkbox"/> |
| 6 | C. SRINIVASAN, "Generation of hydrogen by splitting of water confined in carbon nanotubes with a camera flash," March 25, 2006, Current Science, Vol. 90, No. 6, pp. 756-57. | <input type="checkbox"/> |
| 7 | KEFU FU et al., "Deuterium attachment to carbon nanotubes in deuterated water," March 20, 2004, J. Am. Chem. Soc., Vol. 126, No. 14, pp. 4669-75. | <input type="checkbox"/> |
| 8 | DENG-ZHU GUO et al., "Visible-light induced water-splitting in channels of carbon nanotubes," Jan. 7, 2006, J. Phys. Chem. B, Vol. 110, No. 4, pp. 1571-75. | <input type="checkbox"/> |
| 9 | HENGZHONG ZHANG, et al., "Water-driven structure transformation in nanoparticles at room temperature," 2003, Nature Publishing Group, pp. 1025-29. | <input type="checkbox"/> |
| 10 | National Institute of Standards and Technology, Center for Neutron Research, "Exohydrogenated Single-Wall Carbon Nanotubes," (6 pages). | <input type="checkbox"/> |

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| Examiner Signature | /Sean Burke/ | Date Considered | 07/02/2013 |
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| Application Number | 13591162 |
| Filing Date | 2012-08-21 |
| First Named Inventor | Christopher H. COOPER |
| Art Unit | 1736 |
| Examiner Name | TBD |
| Attorney Docket Number | 1112.0001-05000 |

CERTIFICATION STATEMENT

Please see 37 CFR 1.97 and 1.98 to make the appropriate selection(s):

- ☐ That each item of information contained in the information disclosure statement was first cited in any communication from a foreign patent office in a counterpart foreign application not more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e)(1).

OR

- ☐ That no item of information contained in the information disclosure statement was cited in a communication from a foreign patent office in a counterpart foreign application, and, to the knowledge of the person signing the certification after making reasonable inquiry, no item of information contained in the information disclosure statement was known to any individual designated in 37 CFR 1.56(c) more than three months prior to the filing of the information disclosure statement. See 37 CFR 1.97(e)(2).


- ☐ See attached certification statement.
- ☐ The fee set forth in 37 CFR 1.17 (p) has been submitted herewith.
- ☒ A certification statement is not submitted herewith.

SIGNATURE

A signature of the applicant or representative is required in accordance with CFR 1.33, 10.18. Please see CFR 1.4(d) for the form of the signature.

| | | | |
|------------|---------------------------------|---------------------|------------|
| Signature | /Louis Troilo, Reg. No. 45,284/ | Date (YYYY-MM-DD) | 2013-05-02 |
| Name/Print | Louis Troilo | Registration Number | 45,284 |

This collection of information is required by 37 CFR 1.97 and 1.98. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 1 hour to complete, including gathering, preparing and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. **DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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| Search Notes  | Application/Control No. 13591162 | Applicant(s)/Patent Under Reexamination COOPER ET AL. |
| | Examiner SEAN P BURKE | Art Unit 3646 |

| CPC- SEARCHED | | |
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| Symbol | Date | Examiner |
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| CPC COMBINATION SETS - SEARCHED | | |
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| US CLASSIFICATION SEARCHED | | | |
|----------------------------|----------|----------|----------|
| Class | Subclass | Date | Examiner |
| 376 | 100 | 7/2/2013 | SPB |

| SEARCH NOTES | | |
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| Search Notes | Date | Examiner |
| Reviewed three previous actions. | 7/2/2013 | SPB |

| INTERFERENCE SEARCH | | | |
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| SERIAL NUMBER | FILING or 371(c) DATE RULE | CLASS | GROUP ART UNIT | ATTORNEY DOCKET NO. |
|---------------|----------------------------------|-------|----------------|------------------------|
| 13/591,162 | 08/21/2012 | 376 | 3646 | 1112.0001-05000 |

APPLICANTS
 Christopher H. Cooper, Windsor, VT;
 James F. Loan, Turners Falls, MA;
 William K. Cooper, Santa Fe, NM;
 Alan G. Cummings, Hartland, VT;

**** CONTINUING DATA *******
 This application is a CON of 12/898,807 10/06/2010 ABN
 which is a CON of 12/258,568 10/27/2008 ABN
 which is a CON of 11/633,524 12/05/2006 ABN
 which claims benefit of 60/741,874 12/05/2005
 and claims benefit of 60/777,577 03/01/2006

**** FOREIGN APPLICATIONS *******

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|--------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|---------------------------------------|-------------------------------------|-----------------------------------|----------------------------------------|

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TITLE
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| 13/591,162 | 08/21/2012 | Christopher H. Cooper | 1112.0001-05000 |

CONFIRMATION NO. 1832

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| INFORMATION DISCLOSURE STATEMENT BY APPLICANT (Not for submission under 37 CFR 1.99) | Application Number | | 13591162 | |
| | Filing Date | | 2012-08-21 | |
| | First Named Inventor | Christopher H. COOPER | | |
| | Art Unit | 1736 | | |
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| | Attorney Docket Number | 1112.0001-05000 | | |

U.S.PATENTS

| Examiner Initial* | Cite No | Patent Number | Kind Code ¹ | Issue Date | Name of Patentee or Applicant of cited Document | Pages,Columns,Lines where Relevant Passages or Relevant Figures Appear |
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| | 1 | 20080251735 | A1 | 2008-10-16 | Putterman et al. | |
| | 2 | 20050238565 | A1 | 2005-10-27 | Sullivan | |
| | 3 | 20060072697 | A1 | 2006-04-06 | Proctor | |
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|---|---------------|----|----|------------|-------------|--------------------------|
| 1 | WO2005/001845 | WO | A2 | 2005-01-06 | Rosen | <input type="checkbox"/> |
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| 3 | EP1551032 | EP | A1 | 2005-07-06 | Arata | <input type="checkbox"/> |
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| 5 | WO90/13129 | WO | A2 | 1990-11-01 | Hagelstein | <input type="checkbox"/> |
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| | 1 | International Search Report for related International Application PCT/US2006/045753, dated November 6, 2007. | <input type="checkbox"/> |
| | 2 | International Search Report and Written Opinion for related International Application PCT/US2011/066992, dated April 5, 2012. | <input type="checkbox"/> |
| | 3 | MELECHKO et al., "Vertically aligned carbon nanofibers and related structures: Controlled synthesis and directed assembly," Journal of Applied Physics, No. 97, 2005, pp. 1-39. | <input type="checkbox"/> |

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|----|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|
| 4 | NAGUIB et al., "Observation of Water Confined in Nanometer Channels of Closed Carbon Nanotubes," Oct. 14, 2004, Nano Letters, Vol. 4, No. 11, pp. 2237-43. | <input type="checkbox"/> |
| 5 | ZIDAN et al., "Doped Carbon Nanotubes for Hydrogen Storage," 2003, Hydrogen, Fuel Cells, and Infrastructure Technologies, pp. 1-4. | <input type="checkbox"/> |
| 6 | C. SRINIVASAN, "Generation of hydrogen by splitting of water confined in carbon nanotubes with a camera flash," March 25, 2006, Current Science, Vol. 90, No. 6, pp. 756-57. | <input type="checkbox"/> |
| 7 | KEFU FU et al., "Deuterium attachment to carbon nanotubes in deuterated water," March 20, 2004, J. Am. Chem. Soc., Vol. 126, No. 14, pp. 4669-75. | <input type="checkbox"/> |
| 8 | DENG-ZHU GUO et al., "Visible-light induced water-splitting in channels of carbon nanotubes," Jan. 7, 2006, J. Phys. Chem. B, Vol. 110, No. 4, pp. 1571-75. | <input type="checkbox"/> |
| 9 | HENGZHONG ZHANG, et al., "Water-driven structure transformation in nanoparticles at room temperature," 2003, Nature Publishing Group, pp. 1025-29. | <input type="checkbox"/> |
| 10 | National Institute of Standards and Technology, Center for Neutron Research, "Exohydrogenated Single-Wall Carbon Nanotubes," (6 pages). | <input type="checkbox"/> |

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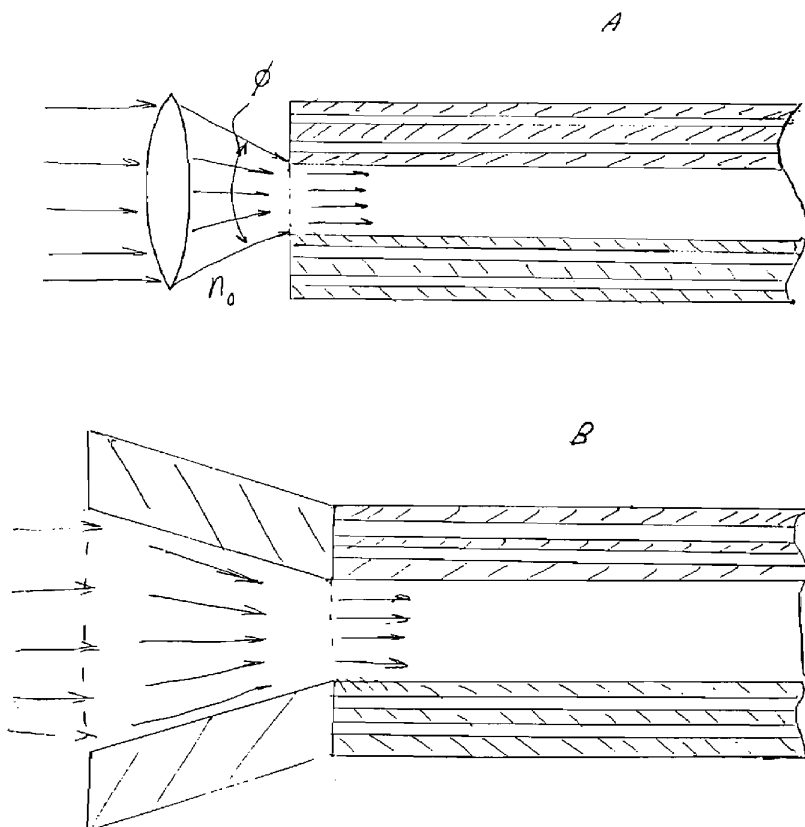
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[Continued on next page]

(54) Title: FUSION APPARATUS AND METHODS



(57) Abstract: Improved apparatus adapted to utilize available fuels and components to produce practical nuclear fusion in a comparatively confined space. In an exemplary embodiment, one or more glass fibers are used as a containment medium for the nuclear fuel (e.g., Deuterium or Lithium). The fibers are also optionally tapered and porous in order to permit introduction of gaseous fuel along a portion of their length. A high-intensity energy source (e.g., pulsed femto-second laser) is used to excite and contain the fuel to fusion temperature through, *inter alia*, pondermotive forces generated within the fiber(s). The effluent from the device can be used for any number of purposes, such as to drive a magneto-hydrodynamic generator in order to generate electricity.



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FUSION APPARATUS AND METHODS

Priority

5 The present application claims priority to U.S. Provisional Patent Serial No. 60/478,699, entitled "Fusion Apparatus And Methods" filed June 13, 2003, and U.S. Serial No. 10/_____ of the same title, filed June 10, 2004, both incorporated herein by reference in their entirety.

Background of the Invention

1. Field of the Invention

The present invention relates generally to physics, and particularly to, *inter alia*, improved apparatus and methods for producing and harnessing nuclear fusion.

2. Description of Related Technology

15 Nuclear fusion is a well understood process whereby, in one exemplary configuration, light (low-Z) atomic species are "fused" so as to form a heavier species, such as where two Hydrogen (H) isotopes are fused to form Helium (He) atoms. The Hydrogen bomb is one example of a large-scale (largely uncontrolled) fusion reaction, as is the sun.

The benefits of fusion energy include: (i) much energy with abundant hydrogen fuel; (ii) safe operations with no potential for uncontrolled chain reactions; (iii) little and short-lived radioactive waste; and (iv) little or no environmental impact.

25 Control of such fusion reactions, however, has proven elusive. Numerous different approaches to creating and sustaining a fusion reaction have been proffered over time, yet none have provided both the desired degree of productive energy output (especially in comparison to energy input to create and sustain the reaction for any appreciable period of time) and level of practicality or cost-efficiency which would permit wide-spread use of fusion technology. A variety of technological challenges are presented in attempting to harness fusion, which can exceed temperatures of 1E08 F. As such temperatures, literally
30 any known material will cease to exist in its original form (e.g., dissociate), and even fundamental magnetic and electric field properties can be altered. Magnetic containment approaches such as the well-known Tokamak (discussed below) and Spheromak have all been only marginally successful at even generating a fusion event, let alone sustaining one

for any appreciable period of time, or even remotely approaching a practical implementation in terms of size, cost, or most importantly energy balance (i.e., energy in versus energy out). Similar limited results have been obtained by high-energy laser-pumped solutions such as those used by Lawrence Livermore National Laboratories (LLNL), and the so-called “Z-pinch” fusion accelerator device of Sandia National Laboratories. Particular aspects of these approaches are described subsequently herein.

Starting in the early 1990s, fusion research took a new direction by using physically large, high power lasers to ignite the reactions. Two of the most powerful and costly lasers systems, “Shiva” and “Nova” were developed at the Lawrence Livermore National Laboratory (LLNL). The largest, Nova, is as long as a football field and three stories high. It uses ten lasers focused onto a 1 mm diameter fuel target, and has produced peak powers of 10^{14} watts. In 1994, Nova reached the Lawson criterion for net energy production fusion (see discussion below), but at a temperature too low for fusion ignition.

In 1999, the laser approach produced a major milestone (per T. Ditmire et al at the Lawrence Livermore National Laboratory, and G. Mourou at the University of Michigan). New, femto-second lasers, producing peak powers on the order of 10^{16} to 10^{20} watts/cm², created nuclear fusion from explosions of laser heated deuterium clusters, in times less than 35 femto-seconds. These were, in a real sense, sub-micron sized hydrogen bombs. The fusions of sub-micron sized deuterium clusters were produced with Titanium-Sapphire lasers that could fit onto a table top. The by-products of the reactions include 2.45 MeV neutrons and energetic, charged alpha particles (nuclei of Helium). The process has been named “table top fusion”.

The reactors for creating controlled nuclear fusion have generally been of two main varieties. These are the magnetic confinement reactor and the inertial confinement reactor.

Magnetic confinement reactors confine the hot fusion plasmas by magnetic fields. These fields keep the plasma particles perpetually looping in circles and helical paths around magnetic field lines, and are typified by the Russian tokamak design. Examples of this approach are the TFTR (Tokamak Fusion Test Reactor) at Princeton Plasma Physics Laboratory, and the tokamak at General Atomics Corporation in La Jolla, CA. In essence, magnetic forces on the plasma particles keep them away from the walls of the containment.

In inertial confinement, the strategy is to put extremely high energy density beams (as from lasers) into a small pellet of fuel such as deuterium, or a mixture of deuterium and tritium, over very short temporal durations. This causes nuclear fusion in the material, in a

short enough time so that the fuel pellets cannot move appreciably. Here, "short duration" refers to reaction times less than 50 femto-seconds (50×10^{-15} sec). This was the approach used by Lawrence Livermore in 1999, with the aforementioned femto-second laser. This approach has significant utility, although laser confinement also plays a role.

5 Confinement is necessary to keep the hot plasmas from touching the walls of the containers. The walls can be destroyed by the plasma, and in turn, they can quench the nuclear reactions. The plasma temperatures involved are typically 50-100 million degrees Kelvin, which are too high to be contained by any known material.

10 In the current state-of-the-art fusion reactor designs, the neutrally charged, fusion neutrons will be absorbed in a boiler to heat water. The resulting steam powers a conventional turbine electric generator. The charged alpha particles from the fusion reactions stay within the plasma, and will be used to self-heat the plasma to even higher temperatures.

15 The following references are representative of the prior art in various disciplines of nuclear fusion technology, each of the following references being incorporated herein by reference in its entirety.

20 U.S. Patent No. 3,940,617 to Farnum, et al. issued February 24, 1976 entitled "Method for nondestructive fuel assay of laser fusion targets" discloses a method for nondestructively determining the deuterium and tritium content of laser fusion targets by counting the X-rays produced by the interaction of tritium beta particles with the walls of the micro-balloons used to contain the deuterium and tritium gas mixture under high pressure. The x rays provide a direct measure of the tritium content and a means for calculating the deuterium content using the initial known D-T ratio and the known deuterium and tritium diffusion rates.

25 U.S. Patent No. 3,946,240 to Roberts, et al. issued March 23, 1976 entitled "Energetic electron beam assisted fusion neutron generator" discloses an energetic electron beam fusion neutron generator in which a plasma is induced by a plasma generator to produce neutrons and to increase the number of neutrons produced, an electron source is guided to the produced plasma to further heat the plasma and produce an even greater
30 number of neutrons. The inner electrode of the plasma generator utilizes the interaction of the beams self magnetic field with the inner surface of the inner electrode to guide the electron source to the plasma.

U.S. Patent No. 3,959,659 to Roberts, et al. issued May 25, 1976 entitled "Intense, energetic electron beam assisted fusion neutron generator" discloses an energetic electron beam assisted fusion neutron generator which comprises a plasma generator and an electron source interconnected by a pinch tube and control means for the plasma generator, electron
5 source, and pinch tube to cause the electron source to be focused on the plasma from the plasma generator and to cause the electron source to be transmitted to the plasma of the plasma generator at the appropriate time to cause a maximum amount of neutrons to be produced by the interaction of the outputs of the plasma generator and the electron source through an appropriate gas filling the plasma generator.

10 U.S. Patent No. 3,991,309 to Hauer issued November 9, 1976 entitled "Methods and apparatus for the control and analysis of X-rays" discloses a fast X-ray excitation processes such as occur during nuclear fusion reactions where high energy laser pulses hit a target, as for the purpose of stimulating atomic emission, may be analyzed by interposing a crystal in the path of the X-rays. The X-rays are transmitted through this crystal by means of the
15 anomalous transmission or Bormann effect. A periodic strain field is established in the crystal to enable or inhibit anomalous transmission.

U.S. Patent No. 3,997,435 to Farnum, et al. issued December 14, 1976 entitled "Method for selecting hollow microspheres for use in laser fusion targets" discloses hollow
20 microspheres having thin and very uniform wall thickness useful as containers for the deuterium and tritium gas mixture used as a fuel in laser fusion targets. Hollow microspheres meeting requirements may be separated from the unsuitable ones by subjecting the commercial lot to size and density separations and then by subjecting those hollow microspheres thus separated to an external pressurization at which those which are aspherical or which have nonuniform walls are broken and separating the sound hollow
25 spheres from the broken ones.

U.S. Patent No. 4,000,036 to Ensley issued December 28, 1976 entitled "Plasma control and utilization" discloses a plasma is confined and heated by a microwave field resonant in a cavity excited in a combination of the TE and TM modes while responding to the resonant frequency of the cavity as the plasma dimensions change to maintain operation
30 at resonance. The microwave field is elliptically or circularly polarized as to prevent the electromagnetic confining field from going to zero. A high Q chamber having superconductive walls is employed to minimize wall losses while providing for extraction of thermonuclear energy produced by fusion of nuclei in the plasma.

U.S. Patent No. 4,017,290 to Budrick, et al. issued April 12, 1977 entitled "Method and apparatus for making uniform pellets for fusion reactors" discloses a method and apparatus for making uniform pellets for laser driven fusion reactors which comprises selection of a quantity of glass frit which has been accurately classified as to size within a
5 few microns and contains an occluded material which gasifies and expands when heated.

U.S. Patent No. 4,021,253 to Budrick, et al. issued May 3, 1977 entitled "Method for manufacturing glass frit" discloses a method of manufacturing a glass frit for use in the manufacture of uniform glass microspheres to serve as containers for laser fusion fuel to be exposed to laser energy which includes the formation of a glass gel which is then dried,
10 pulverized, and very accurately sized to particles in a range of, e.g., 125 to 149 microns.

U.S. Patent No. 4,021,280 to Rinde, et al. issued May 3, 1977 entitled "Method of making foam-encapsulated laser targets" discloses foam-encapsulated laser fusion targets fabricated by suspending fusion fuel filled shells in a solution of cellulose acetate, extruding the suspension through a small orifice into a bath of ice water, soaking the thus formed
15 shell containing cellulose acetate gel in the water to extract impurities, freezing the gel, and thereafter freeze-drying wherein water and solvents sublime and the gel structure solidifies into a low-density microcellular foam containing encapsulated fuel-filled shells.

U.S. Patent No. 4,034,032 to Hendricks issued July 5, 1977 entitled "Method for foam encapsulating laser targets" discloses foam encapsulated laser fusion targets made by
20 positioning a fusion fuel-filled sphere within a mold cavity of suitable configuration and dimensions, and then filling the cavity with a material capable of producing a low density, microcellular foam, such as cellulose acetate dissolved in an acetone-based solvent. The mold assembly is dipped into an ice water bath to gel the material and thereafter soaked in the water bath to leach out undesired components, after which the gel is frozen, then freeze-
25 dried wherein water and solvents sublime and the gel structure solidifies into a low-density microcellular foam, thereafter the resulting foam encapsulated target is removed from the mold cavity. The fuel-filled sphere is surrounded by foam having a thickness of about 10 to 100 micron, a cell size of less than 2 micron, and density of 0.065 to 0.6E03 kg/m³.

U.S. Patent No. 4,052,999 to Coultas issued October 11, 1977 entitled "Bumper wall for plasma device" discloses an improved bumper wall enclosing the plasma in a
30 fusion device to smooth the flow of energy from the plasma as the energy impinges upon the bumper wall. The bumper wall is flexible to withstand unequal and severe thermal

shocks and it is readily replaced at less expense than the cost of replacing structural material in the first wall and blanket that surround it.

U.S. Patent No. 4,057,462 to Jassby, et al. issued November 8, 1977 entitled "Radio frequency sustained ion energy" discloses an electromagnetic (E.M.) energy injection method and apparatus for producing and sustaining suprathermal ordered ions in a neutral, two-ion-species, toroidal, bulk equilibrium plasma. More particularly, the ions are produced and sustained in an ordered suprathermal state of existence above the average energy and velocity of the bulk equilibrium plasma by resonant RF energy injection in resonance with the natural frequency of one of the ion species.

U.S. Patent No. 4,058,486 to Mallozzi, et al. issued November 15, 1977 entitled "Producing X-rays" discloses a method of producing X-rays by directing radiant energy from a laser onto a target. Conversion efficiency of at least about 3 percent is obtained by providing the radiant energy in a low-power precursor pulse of approximately uniform effective intensity focused onto the surface of the target for about 1 to 30 nanoseconds so as to generate an expanding unconfined coronal plasma having less than normal solid density throughout and comprising a low-density (underdense) region wherein the plasma frequency is less than the laser radiation frequency and a higher-density (overdense) region wherein the plasma frequency is greater than the laser radiation frequency and, about 1 to 30 nanoseconds after the precursor pulse strikes the target, a higher-power main pulse focused onto the plasma for about 10^{-3} to 30 nanoseconds and having such power density and total energy that the radiant energy is absorbed in the underdense region and conducted into the overdense region to heat it and thus to produce X-rays therefrom with the plasma remaining substantially below normal solid density.

U.S. Patent No. 4,076,990 to Hendry, et al. issued February 28, 1978 entitled "Tube target for fusion neutron generator" discloses a target for a fusion neutron generator consisting of planar arrays of parallel tubes through which a cooling liquid is circulated. The target is relatively thin, and can be used to intercept two ion beams simultaneously, one on the front and the other on the back of the target. Two mixed ion beams, each containing a mixture of deuterium and tritium ions are accelerated into both sides of the water-cooled chromium plated copper-tube target whereby reactions occur yielding 14 MeV neutrons. At typical operating conditions of 170 keV and 300 mA total beam current, the neutron yield with a mixture of deuterium and tritium gas is approximately $6E12$ n/sec for an effective beam spot of 5.5 centimeters diameter.

U.S. Patent No. 4,133,854 to Hendricks issued January 9, 1979 entitled "Method for producing small hollow spheres" discloses a method for producing small hollow spheres of glass, metal or plastic, wherein the sphere material is mixed with or contains as part of the composition a blowing agent which decomposes at high temperature. As the temperature is quickly raised, the blowing agent decomposes and the resulting gas expands from within, thus forming a hollow sphere of controllable thickness. The thus produced hollow spheres (20 to 10E03 micron) have a variety of application, and are particularly useful in the fabrication of targets for laser implosion such as neutron sources, laser fusion physics studies, and laser initiated fusion power plants.

U.S. Patent No. 4,140,601 to Gomberg issued February 20, 1979 entitled "Multi-step chemical and radiation process" discloses a process which utilizes radiation energy, preferably that obtained from a fusion reaction and which includes selecting starting chemical materials having at least two molecules such as calcium bromide and water which contain as a part thereof a desired product H_2 , a by-product O_2 and which chemically form an active material HBr that may be dissociated by radiation. A two-step process permits the radiolytically dissociated Br to react with residual molecules to form and recycle the starting material $CaBr_2$.

U.S. Patent No. 4,142,088 to Hirsch issued February 27, 1979 entitled "Method of mounting a fuel pellet in a laser-excited fusion reactor" discloses laser irradiation means for irradiating a target, wherein a single laser light beam from a source and a mirror close to the target are used with aperture means for directing laser light to interact with the target over a broad area of the surface, and for protecting the laser light source.

U.S. Patent No. 4,145,250 to Ohkawa, et al. issued March 20, 1979 entitled "In situ regeneration of the first wall of a deuterium-tritium fusion device" discloses apparatus wherein the first wall of a deuterium-tritium fusion reactor is regenerated in situ. The first wall substantially surrounds an enclosed reaction region confined within the reaction chamber of the reactor. To regenerate a worn first wall without opening the reactor chamber, a gaseous substance is introduced into the chamber, at least a portion of the gaseous substance comprising material, such as low Z refractory material, suitable for forming the first wall. At least a portion of this material is deposited, as by pyrolysis, in solid form on the first wall to regenerate the first wall, and residual gas is removed from the chamber. The chamber is then recharged with a mixture of deuterium and tritium.

U.S. Patent No. 4,149,931 to Christensen issued April 17, 1979 entitled "Divertor for use in fusion reactors" discloses a poloidal divertor for a toroidal plasma column ring having a set of poloidal coils co-axial with the plasma ring for providing a space for a thick shielding blanket close to the plasma along the entire length of the plasma ring cross section and all the way around the axis of rotation of the plasma ring. The poloidal coils of this invention also provide a stagnation point on the inside of the toroidal plasma column ring, gently curving field lines for vertical stability, an initial plasma current, and the shaping of the field lines of a separatrix up and around the shielding blanket.

U.S. Patent No. 4,172,008 to Fleet issued October 23, 1979 entitled "Nuclear fusion reactor" discloses a rapidly pulsed nuclear fusion reaction system including a firing chamber into which synchronized opposing beams of ionized gas such as deuterium/tritium are injected in the form of ion pulses which are adapted to collide at the mid point of the chamber. The pulsed ion beams are fed through respective orifices across which is applied a relatively high DC voltage. External to the firing chamber is means for generating a pulsed magnetic field interiorly of the chamber along the ion travel path and in synchronism therewith to provide a guiding effect of the two opposing ion beams to the precise center of the firing chamber. At the moment the leading edges of the ion beams meet, an electric arc is developed due to the voltage applied across the orifice.

U.S. Patent No. 4,182,650 to Fischer issued January 8, 1980 entitled "Pulsed nuclear fusion reactor" discloses an invention relates to a nuclear fusion power plant for producing useful electrical energy by nuclear combustion of deuterium and lithium to helium. A large concentric plate capacitor is discharged rapidly through a mass of molten $\text{LiD}_{1-x}\text{T}_x$ ($0 < x < 1$) that is situated at its center. Before this discharge, a conducting path had been thermally preformed between the electrodes by an ac current pulse. The high-temperature, high-pressure plasma is confined by the LiD liquid in a narrow channel. Neutrons are generated, partly by thermonuclear fusion, partly by suprathreshold collisions which result from the well-known sausage instability. Short Li-D-T chain reactions, enhanced by the beryllium content of the electrodes, are also present. The escaping neutrons are absorbed by the surrounding liquid where they breed T, which is then chemically bound, and produce heat. The heat, radiation and mechanical shock are absorbed in the liquid which flows through a heat exchanger in order to energize the associated turbogenerator power plant. After each pulse, the discharge channel vanishes and is homogenized in the liquid.

U.S. Patent No. 4,182,651 to Fischer issued January 8, 1980 entitled "Pulsed deuterium lithium nuclear reactor" discloses a nuclear reactor that burns hydrogen bomb material 6-lithium deuterotritide to helium in successive microexplosions which are ignited electrically and enclosed by this same molten material, and that permits the conversion of the reaction heat into useful electrical power. A specially-constructed high-current pulse machine is discharged via a thermally-preformed highly conducting path through a mass of the molten salt ${}^6\text{LiD}_{1-x}\text{T}_x$ ($0 < x < 1$). In the resulting dense, hot plasma filament primary nucleons are formed by field-accelerated fusion collisions. These hot particles initiate suprathermal multisteped propagating fission-fusion avalanches that heat the plasma by their own released energy up to thermonuclear temperature. The plasma is confined inertially and magnetically. Neutrons escaping sideways are utilized to breed tritium in the surrounding liquid blanket material, for participation in the next pulse.

U.S. Patent No. 4,188,532 to Deckman, et al. issued February 12, 1980 entitled "Method for the non-destructive assaying of laser fusion targets" discloses methods for assay of the tritium fuel content in laser fusion targets and/or to measure the pressurization of laser fusion targets of the type which use deuterium and tritium (DT) gas mixtures, without destroying the targets. The flux of beta particles which emerges from the target is measured with the aid of a gas flow proportional counter. The count rates are related to the tritium content and the pressurization. The tritium content in terms of the mass of the tritium in the target can be derived from the counting rate.

U.S. Patent No. 4,189,346 to Jarnagin issued February 19, 1980 entitled "Operationally confined nuclear fusion system" discloses a system for generating clean controllable inexpensive electrical power by nuclear fusion of light weight atoms and/or isotopes of hydrogen such as deuterium. Fusionable ions are accelerated head-on from many directions through the middle of a reaction chamber. Such ions are produced by especially designed cyclotrons aimed at one another. Since the orbital motion and escape velocity of an ion is controlled by the magnetic field of its originating cyclotron, said ion cannot hit the outer wall of the opposite magnet (which is of equal strength). Hence the system's plasma is operationally contained. The system can produce plasmas of practically any desired average velocity hence temperature; and in densities approaching 10^{20} per cc at the center of the reaction chamber.

U.S. Patent No. 4,199,402 to Ahmed issued April 22, 1980 entitled "Plasma energy production" discloses energy production by generating an ion stream by laser energy and

injecting the ions within a closed loop accelerator. Numerous nodes about the path of the accelerator densify the ions at minimum cross-sections causing substantial kinetic pressure from particles which are accelerated into the nodes together with injected electrons to form a plasma. The accelerator path contains the ions preventing their escape into the atmosphere. The accelerator recycles the ions continuously within the closed loop path for repeated fusion reaction at the nodes.

U.S. Patent No. 4,216,058 to Marwick issued August 5, 1980 entitled "Enhanced fission breeder reactor" discloses a large inertial confinement breeder reactor wherein neutron bursts produced by fusion, fission or combined fission and fusion are contained seriatim in a large chamber. Each burst results from interception of a large, sub-critical free-falling mass by a smaller upward accelerated slug such that the combined assembly is more than prompt-critical. The resulting thermal energy is absorbed by a spray which generally fills the chamber. The innermost portion of the spray comprises a dense slurry of actinides in molten sodium while the outer portions of spray comprise a very dilute slurry of actinides in molten sodium. The collected heated spray also contains the debris of the explosion and travels through a heat exchanger-precipitator means wherefrom dense slurry, lean slurry, precipitate, and thermal energy may be extracted.

U.S. Patent No. 4,217,172 to Mori, et al. issued August 12, 1980 entitled "Coolant system and cooling method utilizing two-phase flow for nuclear fusion reactor" discloses a coolant system and cooling method for a neutron generating reactor, wherein the gas helium is blown in the form of bubbles into the liquid coolant such as liquid metallic lithium in the liquid coolant blanket, thereby removing heat from the liquid coolant.

U.S. Patent No. 4,224,261 to Halpern issued September 23, 1980 entitled "Methods of fabricating microsphere deuterated initiated hydrocarbon polymer target which emit neutrons when irradiated by high energy beams" discloses targets for high energy beams, such as laser beams, produced in laser fusion apparatus. The targets are porous spheres of deuterated hydrocarbon material, particularly deuterated polyethylene. The spheres are small and have diameters in the range of 50 to 300 microns. Higher neutron yields are obtained from these targets than from solid targets of similar materials, (viz., spherical targets of much higher density). Methods of fabricating the targets by forming them into solid spheres, cross linking their molecules and causing them to swell such that the resultant targets have a microscopically small sponge-like structure, are also described.

U.S. Patent No. 4,240,873 to Linlor issued December 23, 1980 entitled "Solenoidal fusion system" discloses apparatus and methods to produce nuclear fusion utilizing fusible material in the form of high energy ion beams confined in magnetic fields. For example, beams of deuterons and tritons are injected in the same direction relative to the axis of a vacuum chamber. The ion beams are confined by the magnetic fields of long solenoids. The products of the fusion reactions, such as neutrons and alpha particles, escape to the wall surrounding the vacuum chamber, producing heat. The momentum of the deuterons is approximately equal to the momentum of the tritons, so that both types of ions follow the same path in the confining magnetic field. The velocity of the deuteron is sufficiently greater than the velocity of the triton so that overtaking collisions occur at a relative velocity which produces a high fusion reaction cross section.

U.S. Patent No. 4,244,782 to Dow issued January 13, 1981 entitled "Nuclear fusion system" discloses the method and apparatus for the confining of a stream of fusible positive ions at values of density and high average kinetic energy, primarily of tightly looping motions, to produce nuclear fusion at a useful rate; more or less intimately mixed with the fusible ions will be lower-energy electrons at about equal density, introduced solely for the purpose of neutralizing the positive space charge of the ions.

U.S. Patent No. 4,246,067 to Linlor issued January 20, 1981 entitled "Thermonuclear fusion system" discloses apparatus and methods to produce nuclear fusion utilizing fusible material in the form of high energy ion beams confined in magnetic fields. For example, beams of deuterons and tritons are injected in the same direction relative to the machine axis, but the deuteron velocity is sufficiently greater than the triton velocity so that the deuterons overtake the tritons at a relative velocity which produces a high fusion reaction cross section. The momentum of the deuterons is approximately equal to the momentum of the tritons so that both types of ions follow essentially the same path. Thus, the deuteron and triton beams, together with electrons for space charge neutralization, constitute a "moving-plasma", in which fusion reactions occur.

U.S. Patent 4,266,506 to Miller issued May 12, 1981 entitled "Apparatus for producing cryogenic inertially driven fusion targets" discloses a technique for producing uniform layers of solid DT on micro-balloon surfaces. Local heating of the target, typically by means of a focused laser, within an isothermal freezing cell containing a low pressure cryogenic exchange gas such as helium, vaporizes the DT fuel contained within the

microballoon. Removal of the laser heating source causes the DT gas to rapidly condense and freeze in a layer which exhibits a good degree of uniformity.

U.S. Patent No. 4,290,848 to Sudan issued September 22, 1981 entitled "Ion-ring ignitor for inertial fusion" discloses apparatus is disclosed for inertial fusion in which a pulse of ions is injected into a magnetic mirror where the ions are trapped in the form of an ion ring which is then magnetically compressed to increase its energy and reduce its dimensions. The compressed ion ring is then accelerated through a guide tube to strike a pellet in a thermonuclear fusion reactor.

U.S. Patent No. 4,297,165 to Breuckner issued October 27, 1981 entitled "Fuel pellets for controlled nuclear fusion" discloses, in connection with a fusion process which can be initiated by a high energy input such as a laser beam, the use of a layer of uranium surrounding the fusion fuel such as deuterium-tritium or a non-cryogenic fuel such as lithium deuterium-lithium tritium. The uranium serves as a tamper layer to contain the fusion fuel and supplement the heating by a fission reaction which not only increases the fusion yield but increases the time of disassembly.

U.S. Patent No. 4,298,798 to Huffman issued November 3, 1981 entitled "Method and apparatus for producing negative ions" discloses a method and apparatus are described for producing negative deuterium ions for use in controlled thermonuclear reactions such as fusion. Negative ions are obtained by bombarding the surface of an ionization electrode with positive ions and extracting negative ions from the electrode. The unique surface layer of the electrode is formed by depositing onto a substrate the products of thermal decomposition of cesium carbonate. This layer, which is easily formed and renewed, is characterized by a very low value of work function of about 1.05 electron volts.

U.S. Patent No. 4,304,627 to Lewis issued December 8, 1981 entitled "Expandable chamber fusion reactor system" discloses a piston is moved by a laser incited fusion reaction such as deuterium-tritium (D-T) to thereby produce an expandable fusion chamber. When a gaseous substance such as CO₂ is presented in the presence of the fusion reaction, it is dissociated into CO and O₂ component mixture and the expansion of the chamber rapidly cools the mixture and quenches the back reaction thereby producing a greater CO yield. Also the piston produces power from the fusion reaction in the form of mechanical energy.

U.S. Patent No. 4,304,645 to Pierini issued December 8, 1981 entitled "Process for removing helium and other impurities from a mixture containing deuterium and tritium, and a deuterium/tritium mixture when purified in accordance with such a process" discloses a

process for removing helium and other impurities from a mixture containing deuterium and tritium. The method comprises: separating from the mixture isotopes of hydrogen in any of their diatomic combined forms; oxidizing the separated isotopes to their corresponding oxides; separating tritium oxide and deuterium-tritium oxide from the oxides thus formed; and electrolyzing the separated oxides to deuterium and tritium. Preferably the impure mixture of deuterium and tritium is a waste product of a fusion reactor, and the purified deuterium/tritium mixture is recycled to the reactor.

U.S. Patent No. 4,314,879 to Hartman, et al. issued February 9, 1982 entitled "Production of field-reversed mirror plasma with a coaxial plasma gun" discloses the use of a coaxial plasma gun to produce a plasma ring which is directed into a magnetic field so as to form a field-reversed plasma confined in a magnetic mirror. Plasma thus produced may be used as a target for subsequent neutral beam injection or other similarly produced and projected plasma rings or for direct fusion energy release in a pulsed mode.

U.S. Patent No. 4,323,420 to Masnari, et al. issued April 6, 1982 entitled "Process for manufacture of inertial confinement fusion targets and resulting product" discloses an ICF target comprising a spherical pellet of fusion fuel surrounded by a concentric shell; and a process for manufacturing the same which includes the steps of forming hemispheric shells of a silicon or other substrate material, adhering the shell segments to each other with a fuel pellet contained concentrically therein, then separating the individual targets from the parent substrate.

U.S. Patent No. 4,333,796 to Flynn issued June 8, 1982 entitled "Method of generating energy by acoustically induced cavitation fusion and reactor therefor" discloses two different cavitation fusion reactors (CFR's). Each comprises a chamber containing a liquid (host) metal such as lithium or an alloy thereof. Acoustical horns in the chamber walls operate to vary the ambient pressure in the liquid metal, creating therein small bubbles which are caused to grow to maximum sizes and then collapse violently in two steps.

U.S. Patent No. 4,342,720 to Wells issued August 3, 1982 entitled "Method and apparatus for generation of thermonuclear power" discloses a thermonuclear fusion reactor assembly consisting of a plurality of TRISOPS theta pinch units arranged in a parallel configuration inside a common magnetic guide field and provided with a common surrounding FLIBE or other suitable molten metal blanket. The primary magnetic guide field is generated by a superconducting magnet assembly surrounding the container in

which the bundle of fusion sticks is mounted. A gas distributing valve mechanism is employed to independently and selectively supply gas and purge same in the respective fusion stick units, and an electrical switching mechanism is employed to similarly independently and selectively energize the fusion stick units in a desired timing pattern.

5 U.S. Patent No. 4,344,911 to Maniscalco, et al. issued August 17, 1982 entitled "Fluidized wall for protecting fusion chamber walls" discloses an apparatus for protecting the inner wall of a fusion chamber from microexplosion debris, x-rays, neutrons, etc. produced by deuterium-tritium (DT) targets imploded within the fusion chamber. The apparatus utilizes a fluidized wall similar to a waterfall comprising liquid lithium or solid
10 pellets of lithium-ceramic, the waterfall forming a blanket to prevent damage of the structural materials of the chamber.

U.S. Patent No. 4,347,621 to Dow issued August 31, 1982 entitled "Trochoidal nuclear fusion reactor" discloses a method and apparatus for the confining of a stream of fusible positive ions at values of density and high average kinetic energy, primarily of
15 tightly looping motions, to produce nuclear fusion at a useful rate; more or less intimately mixed with the fusible ions will be lower-energy electrons at about equal density, introduced solely for the purpose of neutralizing the positive space charge of the ions. Ions under high kinetic energy are introduced into an annular reaction chamber having a primarily axial strong magnetic field and an essentially radial electric field and assume in
20 the chamber a quasi-trochoidal motion in which the kinetic energies in their small diameter looping components of motion are greater by at least an order of magnitude, than the kinetic energies in the relatively slow crossed field advance motions with which the ions circulate circumferentially around the axis of the annular reaction chamber.

U.S. Patent No. 4,349,506 to Rawls, et al. issued September 14, 1982 entitled
25 "Thermomagnetic burn control for magnetic fusion reactor" discloses an apparatus for controlling the plasma energy production rate of a magnetic-confinement fusion reactor, by controlling the magnetic field ripple. The apparatus includes a group of shield sectors formed of ferromagnetic material which has a temperature-dependent saturation magnetization, with each shield lying between the plasma and a toroidal field coil. A
30 mechanism for controlling the temperature of the magnetic shields, as by controlling the flow of cooling water therethrough, thereby controls the saturation magnetization of the shields and therefore the amount of ripple in the magnetic field that confines the plasma, to

thereby control the amount of heat loss from the plasma. This heat loss in turn determines the plasma state and thus the rate of energy production.

U.S. Patent No. 4,354,998 to Ohkawa issued October 19, 1982 entitled "Method and apparatus for removing ions trapped in a thermal barrier region in a tandem mirror fusion reactor" discloses a method and apparatus for clearing thermal barrier regions of trapped ions in a tandem mirror fusion reactor apparatus utilizing a bend at each end of the cylindrical plasma chamber within which bend the thermal barrier is positioned. Ions trapped in the thermal barrier are caused by said bend to drift in a direction perpendicular to the incident magnetic field and the direction of centrifugal force, such that said ions are enabled to be collected in a divertor positioned along the ion drift path.

U.S. Patent No. 4,354,999 to Priest issued October 19, 1982 entitled "Plasma confinement" discloses a fusion device wherein a laser beam is focused to the center of a spherical reaction chamber having a mirrored inner surface. The spherical reaction chamber is evacuated and surrounded by a concentric lithium jacket which is surrounded by a concentric cryogenic jacket in which is immersed a multi-axis Ioffe bar system. A mixture of deuterium and tritium plasma is continuously introduced into the reaction chamber at a metered rate through the preheat units and compressed at the center of the chamber by the electromagnetic field created by the superconductive Ioffe bar system. This mixture is ignited by the laser beam to create a steady-state, self-sustaining lithium blanket. Power is controlled by controlling the plasma input rate and energy is coupled out of the device by electromagnetic coupling or by recirculating the lithium through a heat exchanger.

U.S. Patent No. 4,363,775 to Bussard, et al. issued December 14, 1982 entitled "Controlled nuclear fusion apparatus" discloses a fusion power generating device having a relatively small and inexpensive core region which may be contained within an energy absorbing blanket region. The fusion power core region contains apparatus of the toroidal type for confining a high density plasma. The fusion power core is removable from the blanket region and may be disposed and/or recycled for subsequent use within the same blanket region. Thermonuclear ignition of the plasma is obtained by feeding neutral fusible gas into the plasma in a controlled manner such that charged particle heating produced by the fusion reaction is utilized to bootstrap the device to a region of high temperatures and high densities wherein charged particle heating is sufficient to overcome radiation and thermal conductivity losses. The high density plasma produces a large radiation and particle flux on the first wall of the plasma core region thereby necessitating replacement of the core

from the blanket region from time to time. See also U.S. Patent No. 4,367,193 to Bussard issued January 4, 1983 entitled "Modular fusion apparatus using disposable core" and U.S. Patent No. 5,049,350 to Bussard, et al. issued September 17, 1991 entitled "Controlled thermonuclear fusion power apparatus and method".

5 U.S. Patent No. 4,370,295 to Bussard issued January 25, 1983 entitled "Fusion-fission power generating device having fissile-fertile material within the region of the toroidal field coils generating means" discloses a fusion-fission reactor having a plasma containing toroidal fusion region for producing high energy neutrons from fusion reactions and a region external to the fusion region containing material which is both fissile with
10 respect to high energy neutrons and fertile with respect to low energy neutrons. The device comprises a toroidal field generating means and a region of fissile-fertile material positioned within the region of the toroidal field generating means. The toroidal field generating means is positioned substantially adjacent the toroidal fusion region.

U.S. Patent No. 4,380,855 to Deckman, et al. issued April 26, 1983 entitled
15 "Method for filling hollow shells with gas for use as laser fusion targets" discloses hollow shell laser fusion targets, such as glass microballoons, filled with gases of the type which do not permeate through the wall of the balloon. A hole is laser-drilled in the balloon, a plug is placed over the hole and gas is introduced into the balloon through the loosely plugged hole. Thereafter the plug is melted to form a seal over the hole, entrapping the gas within
20 the target. The plug is, for example, a polymer such as crystalline polystyrene, or glass.

U.S. Patent No. 4,381,280 to Roberts issued April 26, 1983 entitled "Method and device for producing nuclear fusion" discloses a triggering device and method for producing nuclear fusion reactions and having two or more intense pulses of high energy electrons derived from a single source and delivered to a target along separate paths but
25 arriving at substantially the same time. The electron beams are produced in the electrode space of an electron accelerator which utilizes a cathode for producing multiple electron beams. Each electron beam is injected into a separate conventional linear pinch discharge. The high energy electron beams follow the pinch discharge and are delivered to the target. The pinch discharge tubes are curved so that each electron beam approaches the target from
30 a different direction for irradiating the target symmetrically. Return conductors strategically located on the outer surface of each pinch discharge tube maintains the curved discharge within the center of the tube and sustains the pinch.

U.S. Patent No. 4,397,809 to Salisbury issued August 9, 1983 entitled "Charged particle machine" discloses apparatus wherein atomic nuclei undergo fusion reactions by forming two beams of fusible ions traveling at fusion producing velocities opposed in rotation along spiral paths having common axes, common radii and occupy common space in a reaction zone for fusion producing collisions of ions in one beam with ions in the other beam. Sources produce the oppositely traveling circumferential beams. Radially directed electric fields are applied to the beams of strength increasing with increasing distance from the sources for beam compression into spiral paths of a common reduced diameter passing through common space in the zone to promote collisions between ions in the oppositely traveling beams as they travel in the common space. See also U.S. Patent No. 4,397,810 issued Aug. 9, 1983 entitled "Compressed beam directed particle nuclear energy generator".

U.S. Patent No. 4,401,618 to Salisbury issued August 30, 1983 entitled "Particle-induced thermonuclear fusion" discloses a nuclear fusion process for igniting a nuclear fusion pellet in a manner similar to that proposed for laser beams uses, an array of pulsed high energy combined particle beams focused to bombard the pellet for isentropically compressing it to a Fermi-degenerate state by thermal blow-off and balanced beam momentum transfer. Each combined particle beam is arranged to produce electric charge neutrality in a volume around the target so that space charge induced expansion is avoided. Each high energy combined beam is produced by merging in neutralizing proportion a convergently focused stream of positive particles and at least one convergently focused stream of negative particles to form an electrically neutralized combined beam having a deBroglie wavelength focal pattern at the region of pellet collision. The momentum and fusible mass of the particle beams reduce the ablation loss and result in a larger fraction of the pellet being available for fusion reaction.

U.S. Patent No. 4,411,755 to Herman, et al. issued October 25, 1983 entitled "Laser-assisted isotope separation of tritium" discloses methods for laser-assisted isotope separation of tritium, using infrared multiple photon dissociation of tritium-bearing products in the gas phase. One such process involves the steps of (1) catalytic exchange of a deuterium-bearing molecule XYD with tritiated water DTO from sources such as a heavy water fission reactor, to produce the tritium-bearing working molecules XYT and (2) photoselective dissociation of XYT to form a tritium-rich product. By an analogous procedure, tritium is separated from tritium-bearing materials that contain predominately hydrogen such as a light water coolant from fission or fusion reactors.

U.S. Patent No. 4,430,291 to Chi issued February 7, 1984 entitled "Packed fluidized bed blanket for fusion reactor" discloses a packed fluidized bed blanket for a fusion reactor providing for efficient radiation absorption for energy recovery, efficient neutron absorption for nuclear transformations, ease of blanket removal, processing and replacement, and on-line fueling/refueling. The blanket of the reactor contains a bed of stationary particles during reactor operation, cooled by a radial flow of coolant. During fueling/refueling, an axial flow is introduced into the bed in stages at various axial locations to fluidize the bed. When desired, the fluidization flow can be used to remove particles from the blanket.

U.S. Patent No. 4,434,130 to Salisbury to February 28, 1984 entitled "Electron space charge channeling for focusing ion beams" discloses a fusion reaction system wherein a compressed spiral beam of electrons forms a cylindrical electron sheath and wherein oppositely directed cylindrical beams of fusible ions are projected through said electron sheath and are forced into a common thin cylindrical path located where the potential gradient in electron sheath is minimum.

U.S. Patent No. 4,440,714 to Rose issued April 3, 1984 entitled "Inertial confinement fusion method producing line source radiation fluence" discloses an inertial confinement fusion method in which target pellets are imploded in sequence by laser light beams or other energy beams at an implosion site which is variable between pellet implosions along a line. The effect of the variability in position of the implosion site along a line is to distribute the radiation fluence in surrounding reactor components as a line source of radiation would do, thereby permitting the utilization of cylindrical geometry in the design of the reactor and internal components.

U.S. Patent No. 4,446,096 to Auchterlonie issued May 1, 1984 entitled "High speed plasma focus fusion reactor" discloses an electrical discharge thermonuclear reactor having a capacitor which is discharged into a reaction chamber through a low inductance distribution circuit funneling discharge current to a focus point in the reaction chamber so that the magnitude of the magnetic field intensity associated with the discharge current is generally inversely proportional to the square of the distance from the focus point. Then the circuit inductance is limited to a minimum value regardless of the absolute maximum distance from the capacitor to the focus point and thus the size of the capacitor. The distribution circuit has two outward-branching, interpenetrating three dimensional circuit networks of opposite polarity conveniently fabricated by stacking conductor plates having a generally cylindrical geometry. The distribution circuit spherically surrounds the reaction

chamber so far as is practical so that the discharge rate, power and energy transfer to the reaction chamber are maximized.

U.S. Patent No. 4,454,850 to Horvath issued June 19, 1984 entitled "Apparatus and method for energy conversion" discloses process and apparatus for liberation of energy by nuclear fusion involving isotopes of hydrogen gas. Highly ionized hydrogen gas containing a higher proportion of deuterium than in naturally occurring hydrogen is pressurized, together with an oxidizing gas within combustion chamber of reciprocating piston and cylinder engine. An electrical discharge within the combustion chamber causes generation of heat by atomic dissociation and exothermal recombination of hydrogen atoms and electrical excitation of ionized gas. Ionized deuterium in the hydrogen gas undergoes a nuclear fusion reaction with consequent liberation of heat energy and remaining hydrogen gas burns in the oxidizing gas to provide control on fusion reaction.

U.S. Patent No. 4,532,101 to Doll issued July 30, 1985 entitled "Articulated limiter blade for a tokamak fusion reactor" discloses a limiter blade for a large tokamak fusion reactor includes three articulated blade sections for enabling the limiter blade to be adjusted for plasmas of different sizes. Each blade section is formed of a rigid backing plate carrying graphite tiles coated with titanium carbide, and the limiter blade forms a generally elliptic contour in both the poloidal and toroidal directions to uniformly distribute the heat flow to the blade. The limiter blade includes a central blade section movable along the major radius of the vacuum vessel, and upper and lower pivotal blade sections which may be pivoted by linear actuators having rollers held to the back surface of the pivotal blade sections.

U.S. Patent No. H24 to Kugel, et al. issued February 4, 1986 entitled "Toroidal midplane neutral beam armor and plasma limiter" discloses for use in a tokamak fusion reactor having a midplane magnetic coil on the inner wall of an evacuated toroidal chamber within which a neutral beam heated, fusing plasma is magnetically confined, a neutral beam armor shield and plasma limiter is provided on the inner wall of the toroidal chamber to shield the midplane coil from neutral beam shine-thru and plasma deposition. The armor shield/plasma limiter forms a semicircular enclosure around the midplane coil with the outer surface of the armor shield/plasma limiter shaped to match, as closely as practical, the inner limiting magnetic flux surface of the toroidally confined, indented, bean-shaped plasma. The armor shield/plasma limiter includes a plurality of semicircular graphite plates each having a pair of coupled upper and lower sections with each plate positioned in intimate contact with an adjacent plate on each side thereof so as to form a closed, planar

structure around the entire outer periphery of the circular midplane coil. The upper and lower plate sections are adapted for coupling to heat sensing thermocouples and to a circulating water conduit system for cooling the armor shield/plasma limiter. The inner center portion of each graphite plate is adapted to receive and enclose a section of a circular diagnostic magnetic flux loop so as to minimize the power from the plasma confinement chamber incident upon the flux loop.

U.S. Patent No. 4,568,509 to Cvijanovich, et al. issued February 4, 1986 entitled "Ion beam device" discloses a nuclear fusion device comprising a condensed phase fuel element and accelerated ion beams which ionize and compress the fuel element and initiate nuclear fusion reactions. In one of the embodiment beams comprising electrons in addition to ions are employed. A method is provided comprising synchronization, acceleration and focusing of the beams on the fuel target. A neutron generator is also provided.

U.S. Patent No. 4,569,819 to David issued February 11, 1986 entitled "Pulsed nuclear power plant" discloses a spherical underground cavity filled with saturated steam or a mixture of saturated steam and coal dust in which a nuclear device is detonated to provide the source of energy. The energy thus released heats the saturated steam to produce superheated steam used to generate power. If coal dust is mixed with the saturated steam in the correct ratio, the rise in temperature caused by the nuclear explosion initiates a chemical reaction between the steam and the coal to produce carbon monoxide and hydrogen. The mixture of carbon monoxide and hydrogen can be used as fuel in an external power plant.

U.S. Patent No. 4,578,236 to Gomei issued March 25, 1986 entitled "Torus type nuclear fusion apparatus using deuterium or tritium as fuel" discloses a torus type nuclear fusion apparatus including a main limiter for contacting plasma generated in a space enclosed by a first wall of a blanket and maintaining the shape of plasma stable, and a sub-limiter arranged between the first wall and the outer circumference of plasma to neutralize helium ion, a product of fusion reaction.

U.S. Patent No. 4,608,222 to Brueckner issued August 26, 1986 entitled "Method of achieving the controlled release of thermonuclear energy" discloses a method of releasing thermonuclear energy by illuminating a minute, solid density, hollow shell of a mixture of material such as deuterium and tritium with a high intensity, uniformly converging laser wave to effect an extremely rapid build-up of energy in inwardly traveling shock waves to implode the shell creating thermonuclear conditions causing a reaction of deuterons and tritons and a resultant high energy thermonuclear burn. Utilizing the resulting energy as a

thermal source and to breed tritium or plutonium. The invention also contemplates a laser source wherein the flux level is increased with time to reduce the initial shock heating of fuel and provide maximum compression after implosion.

U.S. Patent No. 4,618,470 to Salisbury issued October 21, 1986 entitled "Magnetic
5 confinement nuclear energy generator" discloses a fusion reactor including a sphere. A first structure is disposed within the interior of the sphere for producing a magnetic field. A second structure is circumferentially disposed around the exterior of the sphere for producing a countermagnetic field. More structure is provided for injecting a gas containing fusible ions into the sphere. Yet more structure is also provided for heating the gas within
10 the interior of the sphere, and for extracting heat from the sphere.

U.S. Patent No. 4,626,400 to Jassby, et al. issued December 2, 1986 entitled "Variable control of neutron albedo in toroidal fusion devices" discloses an arrangement for controlling neutron albedo in toroidal fusion devices having inboard and outboard vacuum vessel walls for containment of the neutrons of a fusion plasma. Neutron albedo material is
15 disposed immediately adjacent the inboard wall, and is movable, preferably in vertical directions, so as to be brought into and out of neutron modifying communication with the fusion neutrons. Neutron albedo material preferably comprises a liquid form, but may also take pebble, stringer and curtain-like forms.

U.S. Patent No. 4,639,348 to Jarnagin issued January 27, 1987 entitled "Recyclotron
20 III, a recirculating plasma fusion system" discloses apparatus designed to burn boron hydride. Boron hydride has no free neutrons on either side of its reaction equation. This fuel attempts to avoid issues associated with neutron-based fuels, deuterium-tritium (D-T) in particular. D-T gives off 80% of its energy in the form of neutrons. These make the apparatus radioactive; and the neutrons may be used to breed weapons grade fission
25 material. The fuel of this invention cannot be used to make fission bomb material; its product particles are ostensibly safe inert helium particles. B-H fuel is abundant, available and inexpensive. Boron hydride comes in gas, liquid or solid form, stable or unstable. The invention at hand proposes to accelerate macromolecular ions of boron hydride into one another, then reaccelerate the debris ions into one another also. This is to be done by
30 recyclotrons--cyclotrons modified to recirculate a similar device's output. Recyclotrons take advantage of the fact that modest energies to a particle accelerator correspond to larger kinetic temperatures in a plasma.

U.S. Patent No. 4,642,206 to Honig issued February 10, 1987 entitled "Production of spin polarized fusion fuels" discloses methods for producing large, highly nuclear spin-polarized thermonuclear fuels HD, D₂, HT and DT in a state where they can be stored and manipulated for appreciable times at ordinary liquid helium temperatures. Molecular
5 mixtures, radiation treatments, symmetry species conversion catalysts, molecular species spatial arrangements, radio frequency irradiations and anneal programs are given to provide polarized D and polarized T in usable forms in the solid, liquid and high density gas phases.

U.S. Patent No. 4,650,630 to Boyer issued March 17, 1987 entitled "Process and apparatus for producing nuclear fusion energy" discloses an invention where two ion beams
10 are accelerated on coincident paths in high vacuum with particle velocity vectors at 180 degrees relative to one another to increase collision and fusion probabilities. The ion beams may be of the same or of different polarities and may both be the same isotope, or may be respectively of deuterium and tritium. A heat exchange fluid such as liquid lithium is in heat exchange contact with the vacuum chamber to remove energy generated by fusion
15 reactions between colliding and fusing particles of the two beams.

U.S. Patent No. 4,687,618 to Nuckolls, et al. issued August 18, 1987 entitled "Laser-fusion targets for reactors" discloses a laser target comprising a thermonuclear fuel capsule composed of a centrally located quantity of fuel surrounded by at least one or more layers or shells of material for forming an atmosphere around the capsule by a low energy
20 laser prepulse. The fuel may be formed as a solid core or hollow shell, and, under certain applications, a pusher-layer or shell is located intermediate the fuel and the atmosphere forming material. The fuel is ignited by symmetrical implosion via energy produced by a laser, or other energy sources such as an electron beam machine or ion beam machine, whereby thermonuclear burn of the fuel capsule creates energy for applications such as
25 generation of electricity via a laser fusion reactor.

U.S. Patent No. 4,696,781 to Bourque issued September 29, 1987 entitled "Composite first wall for fusion device" discloses a first wall structure for use in a fusion device which surrounds the plasma region and includes a base wall which is substantially continuous. The base wall has an inner surface which faces the plasma region and an outer
30 surface which faces the first wall coolant. The inner surface has a plurality of recesses. The wall structure also includes a number of inserts corresponding in number to the recesses with each insert being received in a respective recess and extending inwardly beyond the

inner base wall surface. The inserts are made of material having a substantially greater heat flux capability than the material from which the base wall is formed.

U.S. Patent No. H446 to Kulsrud, et al. issued March 1, 1988 entitled "Method of controlling fusion reaction rates" discloses a method of controlling the reaction rates of the fuel atoms in a fusion reactor comprises the step of polarizing the nuclei of the fuel atoms in a particular direction relative to the plasma confining magnetic field. Fusion reaction rates can be increased or decreased, and the direction of emission of the reaction products can be controlled, depending on the choice of polarization direction.

U.S. Patent No. 4,729,865 to Busch issued March 8, 1988 entitled "Nuclear fusion reactor" discloses a nuclear fusion reactor serving to contain a totally organized tritium-deuterium plasma by guiding the self-bombarding particles in a resonating path of a particular wavelength and frequency, similar to a radio wave. Under these conditions the electrons ostensibly tend to remain cooler, which reduces plasma radiation energy losses. Energy may be added to the plasma by axially distributed oscillators of the proper frequency, raising the plasma to ignition temperature and densities. Finally the ignited plasma directs its high energy neutrons into strategically located lithium blankets and the ionic energy levels are controlled by causing the plasma to generate an alternating electric current. Various types of alternate fusion reactions are briefly considered.

U.S. Patent No. 4,734,246 to Ohkawa, et al. issued March 29, 1988 entitled "Elongated toroid fusion device" discloses a toroidal fusion device with an elongated axial cross section which is capable of ignition without auxiliary heating and with modest toroidal magnetic field. The device is based on the principle that for elongated toroids the toroidal current density in the plasma at ignition is subject to a limit which is proportional to the product of the elongation and the toroidal magnetic field. The elongation is made greater than about 4. The aspect ratio is preferably between about 3 and 10.

U.S. Patent No. 4,735,762 to Lasche issued April 5, 1988 entitled "Laser or charged-particle-beam fusion reactor with direct electric generation by magnetic flux compression" discloses a high-power-density laser or charged-particle-beam fusion reactor system that maximizes the directed kinetic energy imparted to a large mass of liquid lithium by a centrally located fusion target. A fusion target is embedded in a large mass of lithium, of sufficient radius to act as a tritium breeding blanket, and provided with ports for the access of beam energy to implode the target.

U.S. Patent No. 4,746,484 to Jassby issued May 24, 1988 entitled "Fusion reactor pumped laser" discloses a nuclear pumped laser capable of producing long pulses of very high power laser radiation is provided. A toroidal fusion reactor provides energetic neutrons which are slowed down by a moderator. The moderated neutrons are converted to energetic particles capable of pumping a lasing medium. The lasing medium is housed in an annular cell surrounding the reactor. The cell includes an annular reflecting mirror at the bottom and an annular output window at the top. A neutron reflector is disposed around the cell to reflect escaping neutrons back into the cell. The laser radiation from the annular window is focused onto a beam compactor which generates a single coherent output laser beam.

U.S. Patent No. 4,749,540 to Bogart, et al. issued June 7, 1988 entitled "Demountable tokamak fusion core" discloses a demountable tokamak fusion reactor core in which a demountable central portion contains at least the inner toroidal field producing legs of the tokamak toroidal field coil and the plasma containment vessel. Also in the demountable central portion may be poloidal field coils and a means of heating the plasma or heating and shaping the plasma, e.g., an ohmic heating coil. The outer relatively permanent portion of the fusion reactor contains a blanket system within an opening formed by the current return legs of the toroidal field coil. Different embodiments of the ohmic heating coil could include a bucking cylinder toroidal magnet support.

U.S. Patent No. H508 to Mark issued August 2, 1988 entitled "Hybrid-drive implosion system for ICF targets" discloses hybrid-drive implosion systems for ICF targets which permit a significant increase in target gain at fixed total driver energy. The ICF target is compressed in two phases, an initial compression phase and a final peak power phase, with each phase driven by a separate, optimized driver. The targets comprise a hollow spherical ablator disposed around fusion fuel. The ablator is first compressed to higher density by a laser system, or by an ion beam system, that in each case is optimized for this initial phase of compression of the target. Then, following compression of the ablator, energy is directly delivered into the compressed ablator by an ion beam driver system that is optimized for this second phase of operation of the target. The fusion fuel is driven, at high gain, to conditions wherein fusion reactions occur.

U.S. Patent No. 4,774,065 to Penzhorn, et al. issued September 27, 1988 entitled "Process and apparatus for decontaminating exhaust gas from a fusion reactor fuel cycle of exhaust gas components containing chemically bonded tritium and/or deuterium" discloses a process for decontaminating an exhaust gas from a fusion reactor fuel cycle of exhaust gas

components containing at least one heavy hydrogen isotope selected from tritium and deuterium in compound form, the compound form being ammonia and hydrocarbon, the exhaust gas containing CO and hydrogen isotopes and in which the at least one heavy hydrogen isotope is liberated from its compound, separated out from the exhaust gas and
5 fed back into the fuel cycle.

U.S. Patent No. H554 to Dawson, et al. issued December 6, 1988 entitled "Toroidal reactor" discloses a method for producing fusion power wherein a neutral beam is injected into a toroidal bulk plasma to produce fusion reactions during the time permitted by the slowing down of the particles from the injected beam in the bulk plasma.

10 U.S. Patent No. H627 to Peng issued April 4, 1989 entitled "Spherical torus fusion reactor" discloses a fusion reactor having a near spherical-shaped plasma with a modest central opening through which straight segments of toroidal field coils extend that carry electrical current for generating a toroidal magnet plasma confinement fields. By retaining only the indispensable components inboard of the plasma torus, principally the cooled
15 toroidal field conductors and in some cases a vacuum containment vessel wall, the fusion reactor features an exceptionally small aspect ratio (typically about 1.5), a naturally elongated plasma cross section without extensive field shaping, requires low strength magnetic containment fields, small size and high beta. These features combine to produce a spherical torus plasma in a physics regime which permits compact fusion at low field.

20 U.S. Patent No. 4,853,173 to Stenbacka issued August 1, 1989 entitled "Method of producing fusion reactions and apparatus for a fusion reactor" discloses a method of producing fusion reactions comprising the steps of bringing deuterium ions from an ion source to run in a substantially closed path for accumulation of the ions to a predetermined density, whereupon the ions are deflected towards a reaction center inside this closed path.
25 An apparatus for a fusion reactor includes two annular, coaxially disposed magnets which are disposed to produce magnetic fields in a vacuum tank. The inner magnet produces a homogenous field transversely to the plane in which deuterium ions are intended to circulate prior to reaction, and the outer magnet produces an inhomogenous field which decreases outwardly in radial direction and is also directed transversely to the plane.

30 U.S. Patent No. 4,894,199 to Rostoker issued January 16, 1990 entitled "Beam fusion device and method" discloses a fusion device for the reaction of atomic nuclei, preferably deuterons and tritons, to generate reaction products with kinetic energies convertible to useful energy. First and second sources of first and second positive ions

provide such ions at temperatures in a range where the ions have a substantially optimum cross section for mutual reaction. The respective ions are accelerated to substantially the same mean velocity and formed into respective beams. The beams are neutralized and directed into a portion of a reaction chamber substantially orthogonally of a substantially constant unidirectional magnetic field as first and second polarized beams of respective first and second positive hot ions. The polarization of the first and second polarized beams is drained, preferably by a plasma created in the portion of the reaction chamber, to separate the neutralizing electrons from the respective first and second positive hot ions.

U.S. Patent No. 5,034,952 to Mansfield, et al. issued July 23, 1991 entitled "Laser for high frequency modulated interferometry" discloses a Stark-tuned laser operating in the 119 micron line of CH₃OH has an output power of several tens of milliwatts at 30 Watts of pump power while exhibiting a doublet splitting of about ten MHz with the application of a Stark field on the order of 500 volts/cm. This output power allows for use of the laser in a multi-channel interferometer, while its high operating frequency permits the interferometer to measure rapid electron density changes in a pellet injected or otherwise fueled plasma such as encountered in magnetic fusion devices. The laser includes a long far-infrared (FIR) pyrex resonator tube disposed within a cylindrical water jacket and incorporating charged electrodes for applying the Stark field to a gas confined therein. With the electrodes located within the resonator tube, the resonator tube walls are cooled by a flowing coolant without electrical breakdown in the coolant liquid during application of the Stark field. Wall cooling allows for substantially increased FIR output powers. Provision is made for introducing a buffer gas into the resonator tube for increasing laser output power and bandwidth.

U.S. Patent No. H984 to Brooks, et al. issued November 5, 1991 entitled "Self-pumping impurity control" discloses apparatus for removing the helium ash from a fusion reactor having a D-T plasma comprises a helium trapping site within the reactor plasma confinement device, the trapping site being formed of a trapping material having negligible helium solubility and relatively high hydrogen solubility; and means for depositing the trapping material on said site at a rate sufficient to prevent saturation of helium trapping.

U.S. Patent No. 5,078,950 to Bernadet, et al. issued January 7, 1992 entitled "Neutron tube comprising a multi-cell ion source with magnetic confinement" discloses a sealed neutron tube which contains a low-pressure gaseous deuterium-tritium mixture wherefrom an ion source forms an ionized gas which is guided by a magnetic electron confinement field produced by magnets, which source emits the ion beams which traversed

an extraction-acceleration electrode and which are projected onto a target so as to produce therein a fusion reaction which causes an emission of electrons.

U.S. Patent No. 5,152,955 to Russell issued October 6, 1992 entitled "Storage ring fusion energy generator" discloses intersecting storage rings, of the same type used in high energy nuclear physics research, for power generation. The device is optimized for lower-
5 energy beam particles and higher beam current, adapted with a reaction chamber at the intersection of the rings to collect released fusion energy for conversion to electricity, and equipped with means to recapture scattered accelerated particles and reintegrate them into the focused beams for recirculation through the reaction chamber. The preferred beam
10 particles, deuterium and tritium, are accelerated and injected into and focused by the storage rings, to collide nearly head on in the reaction chamber.

U.S. Patent No. 5,160,694 to Steudtner issued November 3, 1992 entitled "Fusion reactor" discloses a fusion reactor based on the cusped geometry concept in which the problem of indefinite tight plasma containment with inherent stability and high
15 compression of the contained plasma in the reaction zone is addressed by an electric potential pot surrounding the reaction zone and having an ion source at the upper potential pot edge.

U.S. Patent No. 5,160,695 to Bussard issued November 3, 1992 entitled "Method and apparatus for creating and controlling nuclear fusion reactions" discloses an apparatus
20 and method of enhancing nuclear fusion reactions utilizing a plasma, made up of ions and electrons, contained within a region, and enhances the density of the plasma using a collision-diffusion compressional enhancement process. Ion acoustic waves generated within a central region of the system permit increased reflection and scattering of ions and thereby reduces their mean free path within the core region to permit increased ions density
25 sufficient to enhance nuclear fusion reactions within the core.

U.S. Patent No. 5,162,094 to Curtis issued November 10, 1992 entitled "Fusion power generating system" discloses an approach utilizing light weight isotopes of hydrogen and helium. A potential well is created between two accelerating electrodes that, in a vacuum, allows ions from sources to be captured by the potential well. An axial magnetic
30 field as created by solenoid causes the captured ions to pass through an ion focusing region and thus allowing fusion reactions to take place within the region. The magnetic field also confines the trajectory of the fusion products to a series of helixes preventing them from reaching the solenoid walls, but instead forces them to exit the two ends of the solenoid.

U.S. Patent No. 5,182,075 to Gotoh, et al. issued January 26, 1993 entitled "Nuclear fusion reactor" discloses a nuclear fusion reactor having a vacuum vessel in which hydrogen isotope plasma is enclosed and a confining magnetic field generating coil for confining said plasma at a predetermined position in the vacuum vessel. It comprises a low tritium-permeable layer having lower tritium-permeability than that of a cooling metal base for forming a refrigerant passage for cooling the vacuum vessel on at least the surface adjacent to said plasma enclosed and a heat resistant and insulating fire member of the level higher than that of the cooling metal base for thermally shielding said low tritium-permeable layer from the plasma or corpuscular rays is formed on the low tritium-permeable layer.

U.S. Patent No. 5,198,181 to Jacobson issued March 30, 1993 entitled "Stabilizing plasma in thermonuclear fusion reactions using resonant low level electromagnetic fields" discloses particles including fusible nuclei and electrons that are contained in a fusion reaction vessel having a conductive length. The particles individually have a mass and a velocity, and are resonated by a weak magnetic field applied to the vessel at a magnetic flux density set according to a relation equating the gravitational energy of the particles with the electromagnetic energy of the applied magnetic field. The magnetic field can be applied in addition to stronger confinement and heating magnetic fields.

U.S. Patent No. 5,375,149 to Fisch, et al. issued December 20, 1994 entitled "Apparatus and method for extracting power from energetic ions produced in nuclear fusion" discloses an apparatus and method of extracting power from energetic ions produced by nuclear fusion in a toroidal plasma to enhance respectively the toroidal plasma current and fusion reactivity. By injecting waves of predetermined frequency and phase traveling substantially in a selected poloidal direction within the plasma, the energetic ions become diffused in energy and space such that the energetic ions lose energy and amplify the waves. The amplified waves are further adapted to travel substantially in a selected toroidal direction to increase preferentially the energy of electrons traveling in one toroidal direction which, in turn, enhances or generates a toroidal plasma current.

U.S. Patent No. 5,410,574 to Masumoto, et al. issued April 25, 1995 entitled "Internal component of fusion reactor" discloses a fusion reactor having an internal component in which an internal structure assembly is housed in a toric vacuum vessel in an arrangement along a circumferential direction thereof and in which a high-temperature plasma in which hydrogen and hydrogen isotopes are maintained in a plasma state confined

in a toric internal space defined in the internal structure assembly. The internal component includes a cooling structure of a multi-wall structure having multiple walls formed to the internal structure assembly and a flow channel formed in the cooling structure for a cooling fluid for extracting heat caused by plasma and a nuclear reaction.

5 U.S. Patent No. 5,572,559 to Smith, et al. issued November 5, 1996 entitled "Radiography apparatus using gamma rays emitted by water activated by fusion neutrons" discloses radiography apparatus includes an arrangement for circulating pure water continuously between a location adjacent a source of energetic neutrons, such as a tritium target irradiated by a deuteron beam, and a remote location where radiographic analysis is
10 conducted. Oxygen in the pure water is activated via the $^{16}\text{O}(n,p)^{16}\text{N}$ reaction using 14-MeV neutrons produced at the neutron source via the $^3\text{H}(d,n)^4\text{He}$ reaction. Essentially monoenergetic gamma rays at 6.129 (predominantly) and 7.115 MeV are produced by the 7.13-second ^{16}N decay for use in radiographic analysis. The gamma rays have substantial penetrating power and are useful in determining the thickness of materials and elemental
15 compositions, particularly for metals and high-atomic number materials.

U.S. Patent No. 5,818,891 to Rayburn, et al. issued October 6, 1998 entitled "Electrostatic containment fusion generator" discloses an electrostatic containment fusion generator comprising a generally spherical capacitor having an outer plate at ground and a negatively charged inner plate. A reaction chamber, comprised of two pairs of spaced apart
20 permanent magnets, is disposed within the inner plate. An ion source means provides a deuteron beam to enter into a figure-8 orbit between the two pairs of magnets. A Faraday cage exists between the two pairs which neutralizes space charge in the center region of the beam. An arced cut portion on each magnet assists in the beam's entry into the Faraday cage, while a path correction means corrects the effects of the inverse field created by the
25 cut portion.

U.S. Patent No. 5,825,836 to Jarmusch issued October 20, 1998 entitled "Tetrahedral colliding beam nuclear fusion" discloses a nuclear fusion reactor that operates by colliding particle beams from at least four different directions. The beams collide in a matrix that guides the particles to the reaction's center by their mutual electrostatic
30 repulsion. In the preferred embodiment the reactor comprises primarily four high energy particle accelerators. At the reactor's center, the accelerators' four beams intersect at angles of approximately 109.47 degrees. Accelerated to fusion producing velocities, the four particle beams intersect in a high-vacuum reaction chamber. The resulting collision matrix

funnels the accelerated particles into the center of the reaction zone causing some of the fuel particles to fuse rather than to scatter.

U.S. Patent No. 5,895,533 to Kawamura, et al. issued April 20, 1999 entitled “Beryllium-copper bonding material” discloses a material for bonding pure beryllium to a copper alloy. The beryllium-copper material comprises a single layer or multiple layers having a thickness of 0.3-3.0 mm and containing at least 50 atomic % of Cu is inserted between the pure beryllium and the copper alloy to prevent bonding strength from degrading in the bonding process or during operation of a nuclear fusion reactor, by effectively mitigating formation of brittle intermetallic compounds and generation of thermal stress at the bonding interface.

U.S. Patent No. 5,923,716 to Meacham issued July 13, 1999 entitled “Plasma extrusion dynamo and methods related thereto” discloses a plasma extrusion dynamo and methods related thereto. Also featured are fusion reactors using such dynamos and methods. In the methodology of the present invention, a steady-state stream of conductive plasma is forced by pressure or momentum to flow into a magnetic extrusion nozzle made up of converging magnetic field lines so as to form a closed, steady-state current loop within the plasma. The plasma current loop in turn forms a closed set of poloidal field lines that interact with the plasma current to compress and confine plasma in a toroidal volume.

U.S. Patent No. 5,949,835 to Uhm, et al. issued September 7, 1999 entitled “Steady-state, high dose neutron generation and concentration apparatus and method for deuterium atoms” discloses a steady-state source of neutrons produced within an electrically grounded and temperature controlled chamber confining tritium or deuterium plasma at a predetermined density to effect implantation of ions in the surface of a palladium target rod coated with diffusion barrier material and immersed in such plasma. The rod is enriched with a high concentration of deuterium atoms after a prolonged plasma ion implantation. Collision of the deuterium atoms in the target by impinging ions of the plasma initiates fusion reactions causing emission of neutrons during negative voltage pulses applied to the rod through a high power modulator. The neutrons are so generated at a relatively high dose rate under optimized process conditions.

U.S. Patent No. 5,958,105 to Ishitsuka, et al. issued September 28, 1999 entitled “Process for preparing metallic beryllium pebbles” discloses a method for stably producing metal beryllium pebbles each ranging from 0.1 to 1.8 mm in particle diameter and 0.05 to 0.6 mm in crystal grain average diameter. The metal beryllium pebbles obtained by the

invention are excellent not only in tritium emission power but also in anti-swelling property, and are thus useful as a material for nuclear fusion reactors. The metal beryllium pebbles can also be advantageously employed for aerospace structural materials and the like, by utilizing their light weight and high melting point properties.

5 U.S. Patent No. 6,411,666 to Woolley issued June 25, 2002 entitled "Method and apparatus to produce and maintain a thick, flowing, liquid lithium first wall for toroidal magnetic confinement DT fusion reactors" discloses a system for forming a thick flowing liquid metal, in this case lithium, layer on the inside wall of a toroid containing the plasma of a deuterium-tritium fusion reactor. The presence of the liquid metal layer or first wall
10 serves to prevent neutron damage to the walls of the toroid. A poloidal current in the liquid metal layer is oriented so that it flows in the same direction as the current in a series of external magnets used to confine the plasma. This current alignment results in the liquid metal being forced against the wall of the toroid. After the liquid metal exits the toroid it is pumped to a heat extraction and power conversion device prior to reentering the toroid.

15 U.S. Patent No. 6,418,177 to Stauffer, et al. issued July 9, 2002 entitled "Fuel pellets for thermonuclear reactions" discloses fuel pellets for use as targets in a device employing thermonuclear fusion by inertial confinement (laser fusion). The pellets are manufactured from high polymer hydrocarbons in which bound hydrogen has been replaced with tritium. The required polymer is prepared by polymerizing monomer(s) which contain
20 carbon and tritium. The hollow pellets are filled with thermonuclear fuel, e.g., a mixture of deuterium-tritium. To improve the sphericity of the pellets and the uniformity of their wall thickness, manufacture of the pellets is contemplated in the near-zero gravity of space.

U.S. Patent No. 6,611,106 to Monkhorst, et al. issued August 26, 2003 entitled
25 "Controlled fusion in a field reversed configuration and direct energy conversion" discloses a system and apparatus for controlled fusion in a field reversed configuration (FRC) magnetic topology and conversion of fusion product energies directly to electric power. Preferably, plasma ions are magnetically confined in the FRC while plasma electrons are electrostatically confined in a deep energy well, created by tuning an externally applied magnetic field. In this configuration, ions and electrons may have adequate density and
30 temperature so that upon collisions they are fused together by the nuclear force, thus forming fusion products that emerge in the form of an annular beam. Energy is removed from the fusion product ions as they spiral past electrodes of an inverse cyclotron converter.

U.S. Patent No. 6,654,433 to Boscoli issued November 25, 2003 entitled "Method and machine for producing energy by nuclear fusion reactions" discloses an experimental machine for producing low-temperature nuclear fusion reactions, wherein an ion source feeds a flux of positive deuterium ions to a reaction chamber housing a target defined by active elements and by an aggregate of metal sulfate hydrated with heavy water; a pumping assembly being provided to maintain a vacuum in the reaction chamber; and the reaction chamber having an accelerating device for accelerating the positive deuterium ions, and which generates an electric field inside the reaction chamber to convey and accelerate the deuterium ions against the active element of the target in such a manner as to initiate nuclear fusion reactions between the incident deuterium ions and some of the atoms of the active element.

U.S. Patent Application Publication No. 20020080904 to Rostoker, et al. published June 27, 2002 entitled "Magnetic and electrostatic confinement of plasma in a field reversed configuration" discloses a system and apparatus for containing plasma in which plasma ions are contained magnetically in stable, non-adiabatic orbits in a Field Reversed Configuration (FRC) magnetic topology. Further, the electrons are contained electrostatically in a deep energy well, created by tuning an externally applied magnetic field. The simultaneous electrostatic confinement of electrons and magnetic confinement of ions avoids anomalous transport and facilitates containment of both electrons and ions.

U.S. Patent Application Publication No. 20020101949 to Nordberg published August 1, 2002 entitled "Nuclear fusion reactor incorporating spherical electromagnetic fields to contain and extract energy" discloses a nuclear fusion reactor system including a reactor core containing nuclear fusionable material and a plurality of conducting spheres arranged adjacent each other with at least two of said conducting spheres adjacent the reactor core. The reactor core and the conducting spheres form an electro/magnetic circuit such that fusion of fusionable material in the reactor core establishes an electro/magnetic flow around the electro/magnetic circuit.

U.S. Patent Application Publication No. 20020172316 to Matera, et al. published November 21, 2002 entitled "Divertor filtering element for a tokamak nuclear fusion reactor; divertor employing the filtering element; and tokamak nuclear fusion reactor employing the divertor" discloses a divertor for a TOKAMAK nuclear fusion reactor, having at least one target element for intercepting the path of contaminating particles from a toroidal channel in which plasma is formed and confined; and at least one grille structure

interposed between a catch region, for catching the contaminating particles, and the input of a plasma purifying device.

U.S. Patent Application Publication No. 20030002610 to Panarella, published January 2, 2003 entitled "Nuclear fusion and energy conversion apparatus" discloses a system and method for generating electrical energy utilizing nuclear fusion comprised of a containment device, a quantity of plasma with fusible substances in the containment device, the containment device and its contents being adapted for repeated cycle bursts of fusion reactions in response to high energy electronic pulses. The fusion containment device is mounted within a chamber containing a body of fluid such that thermal heat energy originating from the fusion reactions is gathered into the fluid body.

U.S. Patent Application Publication No. 20030031285 to Osipov, et al. published February 13, 2003 entitled "Cryogenic layer of fusion fuel, fuel core and method for fuel core producing" discloses fuel for use with an inertial confinement fusion (ICF) reactor, and more specifically the target with condensed layers of the fuel and the method of its production. The invention enables formation of a transparent cryogenic layer from hydrogen isotopes, which retains its transparency when warmed up from 5K to 16-20K. To produce the above cryogenic layer inside micro spheres the method comprises rapid quenching of finely dispersed liquid state in the presence of the doping elements.

U.S. Patent Application Publication No. 20030223528 to Miley, et al. published December 4, 2003 entitled "Electrostatic accelerated-recirculating-ion fusion neutron/proton source" discloses an electrostatic accelerated-recirculating-ion fusion neutron/proton source. The device acts as a compact accelerator-plasma-target fusion neutron/proton source which can emulate a line-type source. The unit comprises an axially elongated hollow vacuum chamber having an inner and outer wall. Reflectors are located at opposite ends of the vacuum chamber so that their centers lie on the axis of the vacuum chamber. A cathode that is transparent to oscillating particles is located within the vacuum chamber between the reflectors, defining a central volume and having the same axis as the vacuum chamber. Anodes that are transparent to oscillating particles are located near opposite ends of the vacuum chamber between the reflectors dishes and the cathode, having axes coincident with the axis of the vacuum chamber.

U.S. Patent Application Publication No. 20030230240 to Rostoker, et al. published December 18, 2003 entitled "Magnetic and electrostatic confinement of plasma with tuning of electrostatic field" discloses a system and method for containing plasma and forming a

Field Reversed Configuration (FRC) magnetic topology are described in which plasma ions are contained magnetically in stable, non-adiabatic orbits in the FRC. Further, the electrons are contained electrostatically in a deep energy well, created by tuning an externally applied magnetic field. The simultaneous electrostatic confinement of electrons and magnetic
5 confinement of ions avoids anomalous transport and facilitates classical containment of both electrons and ions.

U.S. Patent Application Publication No. 20040017874 to Gray, et al. published January 29, 2004 entitled "Modulated quantum neutron fusion" discloses the production of neutrons by the excitation of hydrogen atom valence electrons to the quantum state of a
10 neutron, the synchronization of the quantity and rate of the production of those neutrons in order to synchronize their half-life decays for use in a fusion reaction, the use of phase alignment of the particle field oscillations to precipitate nuclear binding in a fusion reaction.

In addition to the substantially "hot" fusion techniques described above, so-called "cold" fusion techniques were briefly popularized, as ostensibly providing room-
15 temperature fusion reactions. For example, U.S. Patent Application Publication No. 20030112916 to Keeney, et al. published June 19, 2003 entitled "Cold nuclear fusion under non-equilibrium conditions" discloses a supposed method of producing cold nuclear fusion and a method of preparing a fusion-promoting material for producing cold nuclear fusion. The method of producing fusion includes selecting a fusion-promoting material, hydriding
20 the fusion-promoting material with a source of isotopic hydrogen, and establishing a non-equilibrium condition in the fusion-promoting material.

U.S. Patent Application Publication No. 20030215046 to Hornkohl published November 20, 2003 entitled "Pressure generating structure" discloses a method and apparatus for forming a high pressure zone that can ostensibly initiate a fusion reaction. In
25 accordance with the preferred embodiments, a superheated phase bubble is imploded in a reaction chamber to produce a high pressure region and initiate the fusion reaction. The reaction chamber has sloped edges that focus opposing shock waves created by the imploding phase bubble toward a high pressure reacting region. The liquid is filled with deuterium, tritium, uranium, unstable isotopes, and/or other materials that are susceptible to
30 nuclear or chemical reactions at high pressures.

As of the present date, no such "cold fusion" techniques have been credibly shown to actually provide the stated benefits or any form of nuclear fusion.

Hence, despite the foregoing plethora of different approaches, there is still a tremendous unsatisfied need for practical and effective apparatus and methods for providing controlled nuclear fusion. Such apparatus and methods would provide not only an extremely abundant and clean source of energy for a variety of uses, but also could be adapted for other purposes including, *inter alia*, physics research and use as a weapon or deterrent.

Summary of the Invention

The present invention satisfies the foregoing needs by providing, *inter alia*, improved apparatus and methods for providing controlled nuclear fusion.

In a first aspect of the invention, an improved fusion apparatus is disclosed. In one exemplary embodiment, the apparatus comprises at least one electromagnetic energy source (e.g., pulsed laser) adapted to introduce energy within one or more hollow glass fibers having Deuterium-based fuel disposed therein. Pondermotive forces and other phenomenon create sufficient conditions for fusion within the fiber(s), the effluent therefrom comprising a relativistic-velocity plasma stream.

In a second aspect of the invention, an improved electrical generation apparatus is disclosed. In one exemplary embodiment, the apparatus comprises a magneto-hydrodynamic (MHD) device adapted to utilize the aforementioned relativistic plasma in generating electrical potentials due to *Lorentz* forces.

In a third aspect of the invention, an improved method of generating energy is disclosed. The method generally comprises inducing fusion within a containment; ejecting a high-velocity stream of plasma; and utilizing the plasma stream to generate electricity.

In a fourth aspect of the invention, an improved method of cascaded fusion is disclosed. The method generally comprises: providing a containment; disposing fusible fuel within the containment; inducing fusion within the fuel using a propagating wave source (e.g., laser); and inducing further (cascaded) fusion based at least in part on the propagation of the wave within the containment.

In a fifth aspect of the invention, an improved fusion core apparatus is disclosed. In one exemplary embodiment, the core comprises a micron-range block having a plurality of hollow channels disposed therein in a predetermined pattern. The channels may be tapered if desired. At least a portion of the channels are coated on their interior surfaces with palladium (deuterated), other deuterated metals, fusible compounds, or mixtures thereof, which acts as fuel for fusion when laser excitation energy is introduced into the channels.

In a sixth aspect of the invention, an improved fusion containment fiber is disclosed. In one exemplary embodiment, the improved fiber comprises a glass-based longitudinal hollow fiber of the "holey" type. The fiber is coated on at least a portion of its interior with a palladium or similar coating, and is adapted to receive external fuel (such as adiabatically introduced deuterides).

In a seventh aspect of the invention, an improved fusion fuel configuration is disclosed. In the exemplary embodiment, the fuel comprises a deuterated metal such as palladium or lithium which is coated or impregnated on the interior surfaces of a fusion containment (e.g., the aforementioned hollow core fibers).

In an eighth aspect of the invention, an improved method of introducing nuclear fuels such as hydrogen (e.g., Deuterium) or other fusible fuels into a containment is disclosed. In one exemplary embodiment, the method comprises providing porosity or holes within the walls of the containment, and disposing the fuel within the porous features or holes.

In a ninth aspect of the invention, an improved method of generating high-energy particles and/or electromagnetic energy is disclosed. The method generally comprises inducing fusion within a containment; ejecting a high-velocity stream of plasma (the plasma containing ions, subatomic particles, and electromagnetic energy); and utilizing the plasma stream or parts thereof for any number of purposes including e.g., directed energy weapons.

In a tenth aspect of the invention, an apparatus for disposing nuclear fuel for use in a fusion reaction is disclosed. In one exemplary embodiment, the apparatus comprises one or more expendable fusion "cartridges" containing nuclear fuel which can be selectively inserted into a fusion apparatus, much as the cartridges in a conventional powder-based projectile weapon. The cartridges may also optionally be equipped with various nuclear spin isomers to enhance gamma ray or X-ray production (e.g., wherein the nuclei are spin-aligned according to one or more desired orientations).

In an eleventh aspect of the invention, an improved collider apparatus is disclosed, wherein two or more relativistic plasma effluent beams are directed to collide with one another, thereby producing one or more desired species.

In a twelfth aspect of the invention, an improved gamma ray generating apparatus is disclosed. In one embodiment, "soft" X-rays are directed into a hollow core fiber or other chamber to interact with a specially configured fuel such as charged Hafnium. The

interaction of the X-rays and fuel generates a high-intensity gamma burst out the effluent of the fiber.

Brief Description of the Drawings

5 The features, objectives, and advantages of the invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings, wherein:

Fig. 1 is a graphical representation of the prior art Ditmire, et al. experiment conducted at LLNL.

10 Fig. 2 is a graphical representation of the exemplary deuterium reaction generated using the apparatus of the present invention.

Fig. 3 is a perspective view of a first exemplary embodiment of a fusion core according to the present invention.

15 Fig. 3A is a side cross-sectional view of another exemplary embodiment of a fiber useful with the present invention, having an input focusing lens.

Fig. 3B is a side cross-sectional view of yet another exemplary embodiment of a fiber useful with the present invention, having a taper region at its input.

Fig. 4 is a perspective view of an alternative embodiment of the fusion core of the present invention.

20 Fig. 5 is a cross-sectional view of another alternative embodiment of the fusion core of the present invention, showing a tapering fiber containing a fuel.

Fig. 6 is a cross-sectional view of yet another alternative embodiment of the fusion core of the present invention, showing a central tapering fiber and adjacent fibers with each fiber receiving a laser pulse having a different wavelength.

25 Fig. 7 is a partial cutaway view of another alternative embodiment of the fusion core of the present invention comprising a single lumen fiber containing a fusion fuel.

Fig. 8 is a side plan view of yet another alternative embodiment of the fusion core of the present invention showing a curved configuration of an optical fiber.

30 Fig. 9 is an end perspective view of another alternative embodiment of the fusion core of the present invention showing a fiber having a central larger-diameter lumen surrounded by an array of smaller-diameter fiber lumens.

Fig. 10 is an end perspective view of an alternative embodiment of the fiber shown in Fig. 9, wherein the core comprises multiple fibers configured into an array and having

intermediate material between the lumens through which optical energy may couple into adjacent optical fibers.

Fig. 11 is an end perspective view of an alternative (“holey fiber”) embodiment of the fusion core of the present invention showing a single-lumen fiber having multiple fiber layers each having a different index of refraction from adjacent layers.

Fig. 12 is top plan view of an exemplary fusion core of the present invention showing a circular fiber configuration for recirculation of laser energy and plasma.

Fig. 13 is a top plan view of yet another alternative embodiment of the fusion core of the present invention showing a circular fiber configuration formed with multiple fuel-introduction and laser energy ports.

Fig. 13A is perspective view of yet another alternative embodiment of the fusion core of the present invention showing a helical fiber configuration formed with multiple fuel-introduction ports.

Fig. 13B is perspective view of yet another alternative embodiment of the fusion core of the present invention showing multiple concentric helical fibers.

Fig. 13C is perspective view of yet another alternative embodiment of the fusion core of the present invention showing multiple interlaid helical fibers.

Fig. 13D is plan view of yet another alternative embodiment of a collider apparatus of the present invention showing two substantially coplanar fiber rings.

Fig. 13E is perspective view of yet another alternative embodiment of the collider apparatus showing a three-dimensional configuration of multiple fiber rings.

Fig. 14 is a cross-sectional view of an exemplary embodiment of a self-contained fuel element for use with the fusion apparatus of the present invention.

Fig. 15 is a cross-sectional view of an alternative embodiment of the fusion core of the present invention showing a fiber formed with a number of input fibers.

Figs. 16 A-D are end perspective views of various alternative embodiments of the fibers useful in the fusion core of the present invention.

Fig. 17 is a diagrammatic representation of an alternative embodiment of the fusion core of the present invention showing a fusion core at least partially surrounded by a heat transfer system.

Fig. 18 is a perspective view of an exemplary MHD generator system adapted for using the plasma ion effluent from the fusion core(s) previously referenced.

Detailed Description of the Invention

Reference is now made to the drawings wherein like numerals refer to like parts throughout.

It will be recognized by those of ordinary skill that the embodiments described herein are merely exemplary of the broader concept of providing practical nuclear fusion. Many different variations of physical configuration (some of which are described herein) may be employed consistent with the invention.

It will be further recognized that while the exemplary embodiments are described in terms of fusion fuel sources of hydrogen and various isotopes thereof, the present invention may feasibly be practiced using other species, including many elements and their isotopes which have an atomic weight heavier than hydrogen. For example, lithium, helium, carbon, nitrogen, oxygen, argon, and even iron may be used as the “fuel” for the present invention when properly adapted, whether in elemental or chemical compound form. Similarly, ordinary “light” water can even be used within certain embodiment to provide the necessary fuel.

It will also be appreciated that while described in the context of a magneto-hydrodynamic (MHD) generator, the plasma and particulate/EM output of the exemplary fusion apparatus may be used in a variety of different uses, only one of which is producing electrical energy. For example, the relativistic plasma beam may be used for heating or cutting of materials, ion bombardment of materials, generation of X-rays, gamma rays, or neutrons, for material fabrication, or even conceivably spacecraft propulsion. Myriad different uses for the practical plasma/energy source disclosed herein are possible. Furthermore, as described subsequently herein, the use of an MHD device is merely illustrative of the broader principles of making use of the device effluent.

As used herein, the term “fiber” is meant to include any substantially longitudinal containment structure, including, for example, extruded or drawn glass-based fibers. While certain embodiments of the invention are described in terms of so-called “holey” fibers having a taper or tapered region, it will be appreciated that other types and configurations of fibers may be used consistent with the invention, the foregoing being merely exemplary. For example, one alternate embodiment of the invention utilizes quartz fibers or chambers having no taper. Myriad other configurations and materials are possible.

As used herein, the term “laser” is intended broadly to mean any source of at least partly coherent electromagnetic energy including without limitation optical light devices, X-ray devices, UV-devices, IR devices, and magnetic devices (e.g., MASERs).

As used herein, the term “effluent” refers simply to any energy, matter, or other
5 product of the fusion reaction (or byproducts of associated reactions or physical phenomena).

Overview -

In one aspect, the present invention discloses a fiber-based technology for producing, containing, and controlling light element (deuterium, for example) nuclear
10 fusion reactions, and generating direct electrical power or other useful byproducts from the same reactions. In the exemplary embodiment, the approach uses lasers (e.g., femto-second lasers) to produce high-energy fusion plasma, and a hollow glass fiber technology for confining the fast moving plasma, fueling the nuclear reactions, and generating useful output (e.g., electrical power).

15 In the exemplary embodiment, multiple glass fibers (or other light conducting fibers including, for example, layered polymer fibers, photonic crystal fibers or PCF, etc.) with hollow cores are bundled and fused together to form a “fusion core”. This core has the appearance and light conducting functionality of what is commonly called “crystal” or “holey” fibers. The exemplary fusion core can be small enough to fit onto a tabletop, and
20 contains an integral electrical power generator, to convert fusion plasma energy directly into electrical energy. The electrical generator can be as simple as a coil of electrical conducting wire wrapped around the core as in the winding of an electrical transformer, if desired. The fusion core can be linear in shape, curved, a circle, or even other shapes, such as 3-dimensional helix for example. A circular design allows recirculation of both laser pulses
25 and plasma for a cascade fusion reaction.

The exemplary core has ports, which allow laser light, fusible material, and plasma products to enter or exit. These ports can be, for example, other hollow fibers that are spliced onto the fusion core at its ends, or tangentially at multiple locations in the case of curved or circular shaped fusion cores. Additionally, the fusion core can be made of porous
30 glass, be made porous at elevated temperatures, or have transverse holes to allow more fuel to continuously enter from the sides, and be flow-controlled.

Innovative features of the hollow fibers of the exemplary embodiment are that they can contain a solid fusible material, such as deuterated Lithium (D-Li) or deuterated

Palladium (D-Pd), deposited on the inner walls of the fibers; and porosity (or holes) in the fiber walls to allow external based fuels (such as deuterium gas, light and heavy water, and heavier elements) to enter the hollow core in gas, liquid, or solid forms. Laser beams produce field ionization and fusion reactions in the hollow fibers, and by the laser's presence in adjacent fibers, contribute coupled, pondermotive forces to further accelerate the charged plasma particles down the fibers for additional reactions. As conductors of light energy, the hollow fibers also capture photons radiated by accelerated plasma charges contained within the hollow fibers (e.g., Bremsstrahlung or "breaking" radiation), and confine them to the hollow core where they can add to the existing laser pulses, and further accelerate the charged plasma particles in the fiber core. In the well-known tokamak configuration (as well as others), the radiated photons from circulating/accelerating charges are lost, greatly reducing the power efficiency of the design.

The femto-second lasers initially produce plasma necessary for fusion by the "Wakefield effect", from the fusible fuel placed into the fibers. The plasma travels in the direction of the laser beam, while the laser fields inside the fibers accelerate the charged plasma particles to energies on the order of 100 MeV and higher with their pondermotive (Lorentz) forces. The plasma strikes additional fusible material inside the fibers (for example, Deuterium), and fuel introduced by fiber wall holes or porosity, producing more fusion energy. Energetic alpha particles and electrons from these reactions, and remnants of the laser pulse, continue down the fiber and in a "cascade reaction", heat more fusible fuel and induce more nuclear reactions. The hollow fibers can even be nested and drawn down in a taper if desired, to a "convergence zone" of sub-micron size. The inner tubes contain the plasma, while the outer tubes continuously conduct fresh fusion fuel gas mixtures and laser beams to the convergence zone, where additional fusion takes place.

Additionally, neutrons generated from the fusion reaction can strike introduced Lithium-6 material (e.g., Lithium Deuteride) and breed other species (including Tritium) which, with the Deuterium, can produce additional fusion reactions inside the fibers.

The glass fiber tubes that make up the exemplary fusion core have multiple functions, including (i) acting as light waveguides for the femto-second radiation and confinement; (ii) containing the confined fusion plasma; (iii) containing the solid D-Pd, D-Li, or other fusible fuel; (iv) allowing additional fuel to enter the core through porosity and holes in the fiber walls; and (v) containing an integral MHD (Magneto Hydrodynamic) electrical generator.

Salient aspects of the exemplary embodiment(s) include the use of hollow glass fibers to contain plasmas, laser beams, and deuterium fuels; simultaneous use of both inertial and laser fusion containment methods; use of tapered fibers to intensify laser radiation; use of fiber mode coupling to intensify laser radiation; use of porous glass fiber or glass fibers with holes in the walls, to introduce fusion fuel (such as Deuterium) into the hollow fiber core; use of an integral MHD generator on the fibers, for close proximity to the charged fusion reaction products (the plasma); and use of fusion fuels that include light and heavy water introduced into the fiber cores via fiber porosity and holes in the walls of the tubes. These and other aspects of the invention are now described in detail.

Many of the exemplary embodiments of the present invention are examples of “micro fusion” versus the “macro fusion” approach characteristic of present day technologies in inertial and fast igniter fusion (where large and numerous lasers are used within stadium-sized machines). Herein lies one of the most salient distinctions and improvements over the prior art; i.e., use of containment chambers (e.g., glass fiber configurations) measured in inches or even millimeters rather than hundreds of meters. Costs associated with the exemplary apparatus and methods described herein are at least 3 to 4 orders of magnitude smaller than with their larger predecessors, owing at least in part simply to reduced size and complexity. Similarly, the smaller and simpler components are easier to manufacture, maintain and repair. Working on such a small spatial scale compared to the larger scale configurations at Lawrence Livermore National Laboratory (LLNL) or others further allows the present invention to be disposed on platforms or used in applications previously impossible with the prior art. For example, a fusion power supply such as that described herein can be rendered for use on a land vehicle (e.g., automobile, battle tank, truck, train, etc.), ship, aircraft, spacecraft, and any other number of uses. It is further envisaged that the various aspects of the invention can be further compacted spatially, and even reduced to a much smaller size so as to be effectively “hand held”. Applications would then include personal electronics, “fusion electric batteries or FEB” for electric cars, boats and planes. Such FEB can also be used to power weapons, radar, and communications.

In a weapons capacity, the particle and/or electromagnetic energy “beam” emitted from the discharge of the exemplary device described herein may also feasibly be used as a portable weapon, with reductions in femto-second or other laser/source size as technology advances permitting the weapon to even become hand-held.

Description of Exemplary Embodiments

Various aspects and embodiments of the present invention are now described in detail. However, it is first useful to discuss various aspects of nuclear fusion in general in order to provide additional context for the improvements of the present invention.

Fusion reactors must provide a high enough temperature to enable the fuel particles to overcome the repulsive Coulomb barrier (between protons or deuterons), and to maintain this temperature long enough and with sufficient ion density to get a net yield of energy. A net yield of energy means more energy out than was put into the plasma to heat it.

This net energy out condition is usually stated in terms of the product of ion density (n) and confinement time (τ), and is known as *Lawson's criterion*:

$$\begin{aligned} n\tau &\geq 10^{14} \text{ s/cm}^3 \text{ for deuterium - tritium fusion} \\ n\tau &\geq 10^{16} \text{ s/cm}^3 \text{ for deuterium - deuterium fusion} \end{aligned} \quad \text{Eqn (1)}$$

Confinement time is defined as the time the fusion plasma is maintained at a temperature above the critical ignition temperature. This critical temperature is typically greater than 100 million degrees Kelvin. A close approach to Lawson's criterion has been at the TFTR at Princeton. Ignition temperature was reached, but the ion density was too low for practical benefit.

Since the confinement times associated with the use of femto-second lasers are 10^{-13} to 10^{-14} seconds, the challenge for controlled laser fusion, with a net positive energy balance, is to increase the ion density and confinement times to meet the Lawson criterion. More fusion fuel than that of small pellets (such as those used by the Lawrence Livermore apparatus) is needed, as well as a longer laser confinement time.

In the exemplary embodiment, the present invention overcomes these disabilities by use of solid (e.g., deuterium containing) fuel material inside the glass, fiber tubes. By having this fuel material extend many millimeters along the inside of the tube (and optionally introducing fuel via the tube wall), the present invention advantageously increases the laser confinement and interaction time, as well as the ion density.

When light nuclei such as hydrogen and deuterium are forced together by a pulsed femto-second laser beam, they can fuse with a positive yield of energy. The mass of the combination (resultant) nucleus is less than the sum of the masses of the individual nuclei.

According to the generalized Einstein mass-energy relationship ($E = mc^2$), the decrease in mass appears in the form of useful energy.

One of the optimized hydrogen fusion reactions used in the exemplary embodiment comprises the fusion of two heavy isotopes of hydrogen, deuterium (${}^2_1\text{H}$) and tritium (${}^3_1\text{H}$).

5 This reaction is the most energetic, yielding 17.6 MeV energy. The equation for the reaction is:



10 Byproducts of this reaction are energetic neutrons and helium ions (alpha particles). The reaction requires a relatively low temperature of 40 million degrees K to overcome the coulomb barrier between the deuterium and tritium ions. The deuterium fuel is abundant (ocean water has 1 part in 5000 of the hydrogen as deuterium), and the tritium (a radioactive isotope with a half-life of about 12 years) is “bred” from Lithium-6 by slow
15 neutron bombardment in the reaction:

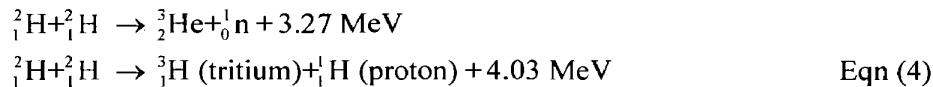


As an option, faster neutrons can also bombard Lithium-7 producing tritium.

20

If a gallon of seawater is viewed as a potential fuel for a hydrogen fusion reactor, the deuterium in it could produce as much fusion energy as approximately 300 gallons of gasoline.

Other hydrogen fusion reactions include two key “D-D” reactions (used by
25 Ditmire’s Deuterium cluster experiment at LLNL):



In the first reaction, the helium-3 product can further react with the deuterium to produce helium-4 plus a proton and 18.3 MeV of energy by the reaction:

30



Aside from the neutron, the hydrogen fusion products are all energetic, charged particles that can be used in an MHD electric power generator (described subsequently herein) in

close proximity to the reactions. Additionally, the neutrons produced can further react with Lithium-6 in the fibers to produce Tritium fuel.

All the fusion reactions which can occur with deuterium can be considered to form a deuterium cycle, and combined into one “super” reaction yielding 43.2 MeV of energy. The combined equation for this reaction is:



The charged by-products are electrons, alpha particles (helium nuclei) and protons, which can all be used in the MHD generator to produce electrical power. The neutrons can also be used to produce more charged particles, by their reactions with, *inter alia*, Lithium.

The best and most recent results demonstrating laser fusion of deuterium are those produced by Ditmire and associates at the Lawrence Livermore National Laboratory, starting in 1999. Ditmire observed the production of fusion neutrons from exploding, frozen, deuterium clusters, using a low energy, high repetition rate (10 Hz) table-top laser. It produced 100 mJ, 35 fs laser pulses; see, e.g., , et al, Nature 398, 492 (1999) (hereinafter “Ditmire”), and J. Zweiback and T. Ditmire, “Femtosecond laser energy deposition in strongly absorbing cluster gases diagnosed by blast wave trajectory analysis”, p. 4545, Physica of Plasmas, American Institute of Physics, 23 February 2001 (“Zweiback”), both incorporated herein by reference in their entirety. Ditmire obtained a yield of about one hundred thousand 2-3 Mev neutrons per laser pulse. Fig. 1 shows the experimental setup of Ditmire. This approach does not have the ability to reach the fusion “ignition” conditions of the larger NIF (National Ignition Facility) laser now under construction at Lawrence Livermore for reasons related to the Lawson Criterion. Specifically, ion density is too low, confinement times too short, and the laser beam diverges too quickly after the interaction with the clusters, to transfer all its energy to the resulting plasma.

Similar approaches to Ditmire are also being undertaken in England, France, Japan, Italy, and Russia, among others. Laser-cluster interaction studies are underway at the Saclay laboratory in France, by M. Schmidt. More recent experiments done in the UK by R. Kodama, use cluster fuels of deuterium and tritium, as well as timed double-pulse lasers. All the investigators generate deuterium cluster fuel for the D-D fusion reaction, by expanding high pressure deuterium gas into a low-pressure “vacuum”. Under these adiabatic conditions, the temperature of the deuterium drops abruptly, and frozen clusters of the gas containing 1 to 10 thousand atoms are formed. The gas expansion nozzle and back

pressure of the vacuum regulate the cluster sizes. The separations of the frozen clusters in this “spritz” of fuel are quite large and dramatically lower the total efficiency of the process.

The deuterium clusters form a bridge between single atoms, molecules, and bulk material, and limit the resulting plasma ion density. In addition, in the Ditmire experiments, the plasma confinement time is limited to the laser transit time through 1-3 millimeters of frozen deuterium gas. Each cluster is only a few millionths of a millimeter in size, but is illuminated in a focused laser beam about 1 micron in size, with an intensity of 10^{20} watts per cm^2 . The inefficiency of this process to ignite many reactions is readily apparent to those of ordinary skill.

Each deuterium cluster becomes in effect a superheated, exploding ball of plasma when struck by a femto-second laser pulse. The ball of plasma expels high-energy charged particles capable of inducing D-D fusion in nearby clusters. Neutron time-of-flight measurements from the clusters to detectors confirm that their measured 2.45 Mev energies are consistent with D-D fusion.

When high intensity laser light passes through the clusters, field ionization is produced, dislodging electrons from the constituent atoms, in the direction of the laser pulse. Although this process is complicated, the laser direction taken by the electrons is dictated substantially by conservation of linear momentum and energy. The initially “stationary” electrons acquire kinetic energy from the incoming photons, in the direction of the laser pulse. The same process on a much lower energy scale is described by the well known Compton scattering phenomenon.

As the electrons move away at “relativistic” speeds (i.e., approximately the speed of light), the atoms become charged deuteron ions, and a large electron current is produced. The electric and magnetic fields of this current contribute to an enormous force on the charged deuterons. The force pulls and accelerates them in the direction the electrons are moving. The electrons acquire energies typically in excess of 100 MeV, and the deuteron ions acquire energies in excess of 15 MeV, all within distances measured in microns. These energies are sufficient to produce fusion.

The high-energy deuteron ions collide and fuse with deuterons from adjacent clusters, producing neutrons, electrons and helium ions of high energy. Fig. 2 illustrates this reaction, showing deuterium ions coming together and fusing to form a helium-3 ion plus a neutron. In the literature, this process is known as “fast ignition fusion” (FIF) because no external electric or magnetic fields are used for confinement.

Several exemplary embodiments of the invention described herein produce laser-induced fusion reactions inside hollow containments (e.g., glass fibers, bored block, etc.). These fibers are made out of fused silica, but may be fabricated out of other materials as well, including without limitation composites, ceramics, polymers, and even porous glass, or glass with sub-micron holes. Lead glass can be used alone or in combination for its ability to stop gamma and X-rays, while "doped" glass may be used as a laser amplifier, to further increase laser field strength and enhance fusion reactions, and also reflect neutrons if desired. Notably, quartz fibers have very low (approaching zero) coefficient of expansion, and hence will not yield to the significant thermal stresses present under rapid heating and/or cooling. Other materials may be used to supplement or replace the hollow fused silica fibers described herein as well, even including for example a "plasma channel" such as that utilized within a conventional prior art Tokamak. As is well known, plasma channels cannot only contain laser beams, but also can cause them to "self-focus" into smaller diameter directed beams with higher power densities. Hence, the present invention can utilize literally any "containment" vessel or structure which can contain the high-energy laser pulses and associated pondermotive forces sufficiently. Different configurations and materials adapted to for enhancing the desired properties will be readily apparent to those of ordinary skill in the laser arts provided the present disclosure.

In alternative configurations of the invention, microtubules (or even so-called "nanostructures") of carbon may also find use as neutron moderators, fuel matrices, and containment vessels, with their unusual properties. Besides graphite and diamond, carbon exists as C-60 in structures primarily composed of hexagons and heptagons whose edges are formed by the carbon-carbon bonds. The first and best known of these structures is the Buckminster-Fullerene C-60 "bucky-ball". The bucky-ball is composed of 20 hexagons and 12 heptagons arranged in the same way as the 'facets' on a soccer ball (i.e., truncated icosahedron).

Each carbon atom in an all-carbon C-60 fullerene network is bonded to three other carbon atoms. The C-60 fullerene network forms a molecule with a cage-like structure and generally aromatic properties. All-carbon fullerene networks contain even numbers of carbon atoms generally ranging from 20 to 500 or more. Larger fullerenes are known as well, with many hundreds of carbon atoms bonded together in a fullerene network. Additionally, "nested" fullerenes (hyperfullerenes) may be prepared wherein one closed fullerene structure is contained within a second larger closed fullerene structure, these

structures being contained in turn within a larger closed fullerene structure. While these hyperfullerene spheroidal carbon molecules are considered to be the most stable forms of fullerenes in terms of cohesive energy per carbon atom, other shapes are possible.

Another useful aspect of the carbon fullerene (e.g., C-60) is the ability to dispose one or more entities such as a fuel structure of impregnated palladium deuteride or other such fuel within the "cage" of the molecule. The truncated icosahedron structure produces a cavity or void within the fullerene, which, depending on the fullerene configuration, may act to contain or house and protect molecules contained therein. Such contained molecule may be captured within the fullerene until one or more carbon-carbon bonds are broken (such as the carbon atom cage being obliterated under the energy of the laser pulses within the fiber lumen), thereby opening a "window" for the extraction or escape of the molecule. Numerous mechanisms for breaking carbon-carbon bonds within a fullerene are known to those of ordinary skill, and accordingly will not be described in detail herein.

The production of C-60 or other fullerene structures containing "captured" molecules or atoms (including radioactive species) is also well known. See for example, U.S. Patent No. 5,350,569 entitled "Storage of Nuclear Materials by Encapsulation in Fullerenes" issued September 27, 1994, and U.S. Patent No. 5,640,705 entitled "Method of Containing Radiation Using Fullerene Molecules" 5,640,705 issued June 17, 1997; U.S. Patent No. 6,171,451 entitled "Method and apparatus for producing complex carbon molecules" issued January 9, 2001; U.S. Pat. Nos. 5,510,098, 5,316,636, 5,494,558 and 5,395,496, which use various processes to vaporize carbon rods, producing carbon atoms that recombine into fullerenes; U.S. Patent No. 5,951,832, "Ultrafine particle enclosing fullerene and production method thereof" issued September 14, 1999, wherein atomic or crystalline species are driven into nanostructure structures using an energetic electron beam; and U.S. Patent No. 5,965,267 entitled "Method for producing encapsulated nanoparticles and carbon nanotubes using catalytic disproportionation of carbon monoxide and the nanoencapsulates and nanotubes formed thereby" issued October 12, 1999, which are each incorporated by reference herein in their entirety.

Furthermore, the shape of all C-60 structures is not necessarily spherical. Football and cigar shaped structures have been reported, and very long capped tubes ("bucky tubes", or carbon nanotubes) have been produced. Nanotubes generally comprise a network of hexagonal graphite rolled up onto itself to form a hollow tube-like structure. These nanotubes have been made with diameters as small as roughly one (1) nanometer. The

length-to-width aspect ratio of nanotubes can be made extremely high, with lengths on the order of a millimeter or more (1E06 nm) compared to diameters on the order of a few nm. Single-walled carbon nanotubes (SWNTs) are produced by any one of several methods, including (i) carbon arcing to vaporize a metal-impregnated carbon electrode; (ii) laser
5 ablation of a heated target; and (iii) catalytic chemical vapor deposition (CCVD), the latter comprising a low temperature technique more suited for large scale production of nanotubes. See, e.g., U.S. Patent No. 5,916,642 entitled "Method of encapsulating a material in a carbon nanotube" issued June 29, 1999, incorporated herein by reference in its entirety.

10 Another deposition technique for either individual or multiple multi-walled carbon nanotubes is based on electron beam lithography. Carbon nanotubes are deposited from the solution phase onto a substrate through lithographically determined openings in an electron beam photoresist layer. The openings may be in size from a few microns upwards. See Yang, Xiaoyu, "*Carbon nanotubes: Synthesis, Applications, and some new aspects*", Thin
15 Films and Nanosynthesis Laboratory, Department of Mechanical and Aerospace Engineering, SUNY at Buffalo, Fall 1999, incorporated herein by reference in its entirety.

It has further been found that selective dissolution of portions of the nanotube (i.e., the so-called "end caps") may be accomplished through exposure of the nanotubes to certain oxidizing substances such as acids. See, for example, U.S. Patent No. 6,090,363,
20 entitled "Method of opening and filling carbon nanotubes" issued July 18, 2000, incorporated herein by reference. Selective dissolution techniques may be used to prepare nanotubes for filling after formation of the tubes.

The foregoing hollow fibers advantageously substantially contain the laser beams, the solid deuterium or other fuel, the photon "force fields", the charged reaction-particles,
25 gaseous fuels used for, e.g., the generation of electrical power, as will be described in greater detail subsequently herein.

The hollow glass fibers referenced above are in the exemplary embodiment arranged in a geometric pattern, with the correct dimensions to allow laser radiation to enter and propagate, and to provide a support for solid, deuterium-containing fuel, coated on the
30 inside walls of the fibers or otherwise introduced into the fiber lumen. This collection of fibers of small (e.g., micron) size are initially prepared from a geometrically similar bundle of millimeter size fibers called a "preform". As is well known in the fiber forming arts, the preform is heated in a furnace, to soften the glass, and pulled or "drawn down" to the

micron sizes. The fibers are reduced in size and fused together to form the glass “fusion core”. By applying air pressure to the preform, the hollow openings or lumens remain at the end of the process. The pulled down core is a miniature in all respects of the larger preform. It will be recognized that other techniques for manufacturing the core may be used
5 consistent with the present invention, however.

The glass fusion core is an example of *Photonic Crystal Fiber* (PCF) technology of the type known in the art. Because of the presence of holes in the glass, the PCFs are also called “holey fibers”. This is a growing commercial technology whose applications are just being realized. See, e.g., R.E. Kristiansen, SPIE, OE Magazine, June, 2002, p.25, “*Guiding*
10 *Light with Holey Fibers-tutorial*” which is incorporated herein by reference in its entirety. Holey fibers provide revolutionary optical characteristics such as for example single-mode operation from the UV to IR spectral regions. The fibers have large mode areas with hollow core diameters greater than 20 microns. Associated with these large areas are numerical apertures (NA) that can reach values of 0.9. This equates to large laser acceptance angles,
15 and high tolerance laser coupling. Dispersion properties can be easily adjusted, and the laser power conducting capacity far exceeds that of conventional fibers. The holey fibers have been shown to be excellent conduits for high power laser energy. Unlike earlier single mode fibers with solid cores that were highly dependent on few material parameters, the PCF represent a highly engineered microstructure, with numerous free parameters to alter optical
20 characteristics. Quite unexpected, the PCF exhibit band-gaps with forbidden frequency zones. The presence of hollow cores in single mode operation advantageously negates the damaging effects of femto-second laser radiation on solid glass cores as in older single mode fibers.

The production of various types of holey fibers is well known, and described for
25 example in U.S. Patent No. 6,577,801 to Broderick, et al. issued June 10, 2003 entitled “Holey optical fibers”; U.S. Patent No. 5,802,236 to DiGiovanni, et al. issued September 1, 1998 entitled “Article comprising a micro-structured optical fiber, and method of making such fiber”; U.S. Patent Application Publication No. 20020118937 to Broderick, et al. published August 29, 2002 entitled “Holey optical fibres”; and U.S. Patent No. 6,661,957 to
30 Levenson, et al. issued December 9, 2003 entitled “Diffusion barriers for holey fibers”, each of which are incorporated herein by reference in their entirety.

Referring now to Fig. 3, a first embodiment of the fusion core of the present invention is shown and generally designated 100. The fusion core 100 includes a body 102

formed with a set of four (4) center hollow cores, or lumens, 104, and surrounded by eight (8) larger diameter hollow cores 106. A series of smaller diameter hollow cores 108 may be formed in body 102 such that body 102 is substantially filled with hollow cores.

In one embodiment of the invention, the aforementioned core is fabricated from a unitary block of glass as opposed to individual fibers. Specifically, a femto-second or other laser under computer control may be used to "etch" or form the aforementioned containment channels (tapered or otherwise) into the block, such processing methods being well known in the art. It will be appreciated that while a "glass" block is used in this embodiment, other suitable materials, such as polymers or even ceramics, may be used in this capacity.

From Fig. 3, it is also to be appreciated that hollow cores 104, 106, and 108 formed with fusion core 100 may be placed in a variety of configurations. For example, a single hollow core, such as hollow core 110 having a larger diameter, may be formed in place of center hollow cores 104. While several examples of configurations of hollow core fibers for the present invention will be discussed herein, such examples are merely exemplary of preferred embodiments, and no limitations as to the particular positioning, relationships, sizes or quantity of hollow cores are to be inferred. Also, the geometric pattern of holes is meant to be indicative of the final structure, but not exact. Likewise, the core dimensions of 10 – 20 microns in this embodiment are only approximate and in no way limiting of the invention.

The fusion core 100 receives an optical radiation source in a first direction 120, such as laser pulses 122 and 124. In a preferred embodiment, the laser pulses 122 and 124 have durations 126 and 128 of approximately 10^{-15} seconds, although shorter or longer pulses may be used within the limitations of causing sufficient energy influx to the core to cause fusion. See e.g., "Relativistic Laser-Plasma Interactions", Donald Umstadter, Univ. of Michigan, Journal of Physics D: Applied Physics (36) 2003 R151-R165, incorporated herein by reference in its entirety, wherein a high power petawatt (10^{15} W/cm²) laser is used to accelerate beams of electrons and protons to MEV energies in the space of short (micron) distances, and their use in igniting thermonuclear fusion, as well as the production of neutrons and positrons.

While pulses 122 and 124 have been shown to have substantially similar durations 126 and 128, it is to be appreciated that this is merely indicative of a preferred embodiment, and that any duration is contemplated herein, including but not limited to constant radiation

sources, those having a varied pulse length or duration, or radiation sources having single pulses, multiple pulses, or pulses that are regularly or irregularly spaced.

Any number of laser energy sources can be used with the present invention. One preferred source comprises so-called "femto-second" lasers, which are well known in the laser arts. See, e.g., U.S. Patent No. 5,400,350 to Galvanauskas issued March 21, 1995
5 entitled "Method and apparatus for generating high energy ultrashort pulses", and U.S. Patent No. 5,377,043 to Pelouch, et al. issued December 27, 1994 entitled "Ti:sapphire-pumped high repetition rate femtosecond optical parametric oscillator", both of which are incorporated herein by reference in their entirety. Such lasers are available from a number
10 of commercial sources, such as Del Mar Ventures of San Diego, CA. In the illustrated embodiment, laser energy wavelengths on the order of between 1.2 and 0.1 micron are used, although it will be recognized that other wavelengths (including into the deep UV or X-ray regions) can be used in certain applications.

The laser pulses 122 and 124 may be striking body 102 normal to fiber cores 104,
15 106 and 108, and 110, along axis 129. Alternatively, laser pulses 122 and 124 may strike the body at an angle 130 along alternate axis 131. The maximum value of this angle may vary as a function of fiber geometry, materials, and other factors. As a result of this tolerance in acceptance angle of the fusion core 100, there is advantageously less concern for precise alignment that is often the case when directing laser beams into conventional
20 solid core single-mode optical fibers. However, somewhat precise alignment between the fiber and the laser energy source (i.e., the incident laser energy wavefront) does couple a maximal amount of energy into the fiber. One method of addressing this issue is to use holey fibers with a hollow core or cores and large numerical aperture (NA), e.g., on the order of 0.7-0.9, thereby allowing easy coupling of "focused", high intensity femto-second
25 laser pulses, into the core with low loss. The holey fiber then permits the propagation of the high intensity laser pulse through the rest of the hollow fiber with low loss and no core damage, as well as permitting the laser pulse to interact with fusion fuel such as deuterium gas.

Such large NA fibers can be coupled to the laser using any number of approaches,
30 including for example the use of a lens or other focusing apparatus (e.g. prism, parabolic reflector, or the like) disposed at the front end of the fiber (see Fig. 3A). Where an optical lens or prism is used, only certain power levels of incident energy can be used since the lens can literally be melted through the application of too high a power. For example, incident

power densities of roughly 10^{15} W/Cm² present an approximate upper limit when using conventional glass-based lenses, although other materials may be used as well. The airspace between the lens 150 and the ingress of the fiber 152 can also be evacuated of air or other impurities if desired, in order to mitigate any diffractive or other effects on beam propagation. The position of the lens (or lenses, where a series or parallel arrangement is used) can also be varied such that the focal length couples properly with the fiber; this parameter can even be adjusted during operation to achieve optimal performance or one or more desired behaviors. Furthermore, the focal point of the lens can be varied within the fiber interior channel (e.g., by slightly tilting the plane of the lens off-axis) in order to focus the laser energy preferentially at one point or side of the fiber, such as to compensate for fiber imperfections, uneven fuel burn or distribution, or the effects of an external field which is not uniform on the fiber.

In another configuration (Fig. 3B), a tapered region 160 is disposed at the ingress of the fiber 152, whether part of the fiber itself or alternatively comprising a different component mated or otherwise coupled to the fiber. In this fashion, higher energy incident laser energy (e.g., 10^{19} W/cm²) can be directly coupled into the fiber, also without perfect alignment for the wavefront and the fiber core aperture. Hence, the taper region acts akin to a funnel, directing the incident energy generally into the fiber wherein the high NA allows the directed energy to be substantially coupled into the interior of the fiber.

Referring now to Fig. 4, an alternative embodiment of the fusion core of the present invention is shown and generally designated 200. The fusion core 200 includes a group of four central hollow fibers 202 each formed with a hollow core 204, and surrounded by a series of outer hollow fibers 206 each formed with a hollow core 208.

Radiation is directed toward the fusion core 200 in a first direction 210, such as an incoming radiation pulse 212. For discussion purposes, this radiation pulse 212 has been represented as a series of parallel radiation sources 214, although this is not required. Each of these radiation sources 214 enters the hollow cores 204 and 208 to provide a radiation energy level within the hollow cores of fibers 202 and 206.

In a preferred embodiment, the radiation energy level of pulse 212 is on the order of 10^{15} - 10^{16} watts/cm². Assuming this value, the radiation energy level within any fiber is approximately the same (at least at the ingress to the fiber before any taper or mode coupling occurs). However, due to the positioning of the fibers 202 and 206 such that portions of the side walls are in contact, a portion of the radiation energy within the outer

fibers 206 will mode-couple into the cores 204 of the inner fibers 202. This coupling will effectively increase the radiation energy level within the inner optical fibers 202. The coupling effect is shown with dashed arrows 220 passing from the core 208 of outer fibers 206 to the cores 204 of inner fibers 202. Fibers exhibiting such coupling are commercially available from a number of sources, such as BlazePhotonics Ltd of the United Kingdom.

Referring again to Figs. 3 and 4, the illumination of the glass fusion cores is in the exemplary embodiment conducted with femto-second laser pulses. The pulse laser illumination strikes the glass, preferably but not necessarily, normally over a region containing the 4 holes 104 with solid deuterium fuel (not shown in Fig. 4), surrounded by 8 empty, but larger holes 106. The intensity of the radiation source is adjusted below the fiber (e.g. glass) damage threshold, but increases through concentration and "mode-coupling" within the core as discussed above. In this regard, fibers with different physical characteristics; e.g., different optical or refractive indices, damage thresholds, physical geometries (such as cross-sectional shapes and tapers) can be used for the inner and outer "tubes" if desired. Such physical variations can be used for example to increase the longevity of the inner tubes, to selectively "steer" the mode-coupled energy from the outer fibers to the inner fibers, etc.

In one embodiment, the 4 central holes are tapered down, to concentrate and increase the laser intensity to a value greater than 10^{18} watts/cm². Because the surrounding 8 holes 106 are in close contact with the inner 4 holes 104, some laser energy transfers from holes 106 to holes 104 through directional mode coupling.

It is noted, however, that even in the absence of tapering, sufficient energy density for fusion can be achieved even with sub-sufficient power density at the ingress of the fiber due to one or both of (i) "self-focusing" of the laser energy by the plasma during pulse propagation, and (ii) mode-coupling between fibers. See, e.g., "Propagation dynamics of femtosecond laser pulses in hollow fiber filled with Argon", Nurhuda, M. et al, RIKEN Review No. 49 (Nov. 2002), incorporated herein by reference in its entirety, wherein a peak intensity as high as 2X that of the input peak intensity was observed due to "refocusing" of the laser pulses at a distance of 12 cm.

The central group of 4 holes 104 may contain, for example, a fuel of deuterated palladium (D-Pd). The solid D-Pd fuel is in the form of thin films deposited onto the walls of the fiber holes, or otherwise introduced into the lumen as discussed elsewhere herein.

The fuel is subject to the laser pulses that directly enter the holes 104, and to the laser energy that enters from the surrounding 8 holes 106, through mode coupling.

It is known that high intensity (e.g., femto-second) laser pulses can destroy glass and most materials. Such lasers are in fact used to etch the interior of solid glass blocks. To use such a laser to illuminate a fusion core requires that the intensity (power density) within glass sections of the core be kept below the damage threshold for the material, or at least for substantial fractions of the operating period of the core. Maximum intensity, of 10^{18} watts/cm² or higher, however, is required for the efficient field ionization of the deuterium fuel and resulting acceleration of the D ions.

This seeming paradox is advantageously solved in the illustrated embodiment by having the maximum photon intensity occur within the holes (lumen) of the core(s). In one variant, this is substantially accomplished by tapering the inner 4 holes 104 to smaller diameters, and transferring additional laser energy into them by "directional coupling"; see, e.g., Integrated Optics, T. Tamir, Ed., *"Semiconductor Components for Monolithic Applications"*, E. Garmire, 243-304, Springer Verlag, New York 1975, which is incorporated by reference herein in its entirety. Such directional coupling allows energy from the outer 8 holes, or hollow fibers, 106 to be coupled preferentially into the inner fibers. With proper optical design, the directional coupling can be made over ninety percent (90%) efficient.

Substantial support exists for the ability of glass and similar fibers to sustain the high energies (i.e., peta-watt and above) associated with femto-second and other high-energy lasers without damage. See, e.g., *"Breakthrough Brings Laser Light to New Regions of the Spectrum"*, National Science Foundation Release 03-01 dated Jan. 2, 2003, (citing Jan 2, 2004 issue of Nature, by S. Backus and R. Bartels of Univ. of Colorado), both incorporated herein by reference in their entirety, wherein a femto-second laser is fired directly into the core of a hollow optical fiber waveguide to produce a tightly collimated EUV light source. The fiber core was filled with Argon gas, which was turned into a UV radiating plasma. The fiber hollow core was also a "modulated, hollow glass tube", and the wall modulations (referred to as "speed bumps") substantially survived the laser pulses without significant damage. See also *"Hollow Fiber Carries Megawatt Pulses"*, Sept. 18 2003 issue of Optics.org (also reported at *Science* 301, 1702), incorporated herein by reference in its entirety, wherein transmitted 75 ps pulse of 5.5 MW in a Xenon-filled hollow core holey fiber is demonstrated. In this reference, the holey fiber (hollow core)

sustains peak powers on the order of 1000 times those of conventional single-mode fibers (solid core).

As yet further support for this proposition, see "Ions Generate 5-nm X-Rays", . Photonics Spectra Magazine, February 2004, p. 24 (citing Jan 23, 2004 issue of Physical Review Letters from the Univ. of Colorado), both incorporated herein by reference in their entirety, wherein a peta-watt laser pulse of intensity 1.3×10^{15} w/cm² was injected into a hollow core fiber (with modulated core) filled with pressurized argon to generate X-rays. The fiber survived this exposure, and appeared to be able to sustain even higher laser intensities.

It will further be recognized that individual ones of the hollow fibers need not be used during each laser pulse. For example, in one alternative embodiment, the laser excitation energy pulses are directed at only a subset of the relevant fibers within the core per interval of time. In this fashion, the fibers undergoing fusion are rotated as a function of time, so as to mitigate secondary thermal effects, mitigate reverse mode-coupling between the center and outer cores, and so forth. In yet another embodiment, the laser energy introduced to each hollow fiber channel (or group thereof) is "tuned" in terms of intensity and/or wavelength in order to optimize performance of the core as a whole, or compensate for asymmetries or variations in energy/plasma density. Myriad other variations on the basic concept of introducing laser energy into a hollow channel disclosed herein will be appreciated by those of ordinary skill provided this disclosure.

In another embodiment, an "insulating plasma" can be generated within certain parts of the lumen (e.g., those proximate to the wall of the fiber). In one embodiment, a Hafnium Dioxide (HfO₂) material is disposed on the interior surfaces of the fiber channel, such as via a CVD or other deposition process, although it may also be introduced via impregnation into the wall, or via diffusion through the wall or ports formed in the wall as described elsewhere herein. This material can be combined with others (e.g., deuterated palladium, etc.) if desired, or disposed in a discrete layer or region of the interior surface of the fiber. As is known (see, e.g., "Petawatt laser opens new realm of plasma physics", OE Report 168, SPIE Web, December 1997 {citing D. Pennington, LLNL}, incorporated herein by reference in its entirety), the HfO₂ forms a plasma when irradiated with sufficient energy intensity, to the point of becoming highly reflective of the incident laser energy at power densities greater than approximately 2×10^{14} W/cm². Accordingly, when the incident and/or mode coupled energy is introduced into the fiber lumen, the HfO₂ experiences sufficient

power density to form a highly reflective plasma “coating” or film on the inside surfaces of the fiber, in essence a plasma ring within the lumen which also further acts to “self-focus” the laser energy. This provides a number of benefits, including reducing leakage of energy from the fiber through the walls, and even some degree of insulation of the fiber walls from the high-intensity laser energy propagating through the fiber lumen.

The directional coupling process is shown schematically with dashed arrows 220 in Fig. 4. The laser illuminated central portion of the fusion core with the 4 tapered fuel fibers is illustrated. The large vertical arrows 214 represent the portion of a femto-second pulse entering all the hollow fibers, with intensity below the damage threshold. The smaller horizontal arrows 220 shown in dashed lines represent the directional coupling of laser energy into the central D-Pd filled fibers 204. It will be recognized by those of ordinary skill that other geometries can be used, such as for example where the D-Pd filled fibers surround larger hollow fibers, and the directional coupling is from the inside out. Alternatively, the “fueled” fibers can be interspersed with the other fibers (e.g., heterogeneous rings) so that coupling occurs not only between the inner and outer “rings” of fibers, but also circumferentially within a ring. More than two rings can be used as well, myriad other such variations being possible.

It will also be recognized that the illustrated embodiments using small diameter hollow-core fibers have another salient advantage relating to their scalability. Specifically, one can in theory utilize a single minute fiber to produce fusion energy; however, that single fiber will have limited installed fuel (or limited uptake of fuel inserted from an external source such as diffusing through the porous fiber). However, by simply adding more similar fibers to the array (and energy sources as required), the energy output can be scaled incrementally. Using larger diameter fibers (and/or more fibers) also scales up the power. Hence, the present invention can be practiced on anything ranging from an extremely small scale to a very large scale, depending on fiber and core sizes and geometries. Multiple cores can also be used together to form even larger arrays of fibers.

Neutron and/or gamma reflectors can also be controllably interposed between the fibers or arrays to control the lateral leakage from the fibers/arrays to their neighbors, much like a control rod controls localized neutron flux within a fission core, the distinction here being that no criticality issues exist with the present invention. Such leakage control may be desirable to control, e.g., material damage (e.g., neutron embrittlement), energy leakage into adjacent fibers, etc. For example, materials such as Beryllium, Deuterium Oxide (D_2O),

⁵⁸Ni/Mo, and/or water can be used to reflect neutrons. Furthermore, the materials can be chosen to selectively tailor the reflection coefficient (fraction) as a function of incident neutron energy, such as where it is desired to allow thermal neutrons to pass substantially unimpeded, yet block fast neutrons (or vice-versa).

Alternatively, however, the neutron or other particle/wave leakage between fibers may be used to reduce the net percentage leakage of energy from the core as a whole. As is well known, as the number of energy radiating “pipes” is increased within a given geometric proximity of one another, the ratio of lost energy to generated energy is reduced, since the surface area (or radius in two dimensions) does not increase as fast as the rate of energy production, especially where mode-coupling of the type previously described herein is present. Hence, in certain configurations, the core of the present invention can be made more efficient through aggregation of a number of different fibers disposed proximate to one another.

It will be recognized that all the hollow fiber configurations discussed herein can also be “potted” or encapsulated in an encapsulant (such as for example a polycarbonate or other polymer, elastomer, or even metal or alloy) of various shapes. This includes, without limitation, encapsulating the fibers as individual strands, as well as encapsulating a fiber “block” such as shown in Fig. 3. For example, the exterior of the fiber core block of Fig. 3 could be encapsulated in a lead shield doped with beryllium or another neutron reflector. The recirculating architectures of Figs. 12-13 may also be encapsulated if desired. This encapsulation protects the comparatively fragile glass fiber technology from accidental damage, makes it easier to position the modules, absorbs leaking neutrons, and make the components safer to handle when in operation. The plastic potting or encapsulation can also include dopants or other forms of materials (such as lead sheets or foil in appropriate locations to absorb X-rays and gamma rays or reflect neutrons), and thus make the module safer to handle or use in non-laboratory applications.

Also, the fibers may be coated with a metallic material if desired, such as aluminum; see, e.g., “Light Constructions: New fabrication technique optimizes excimer-laser light”, S. Bains, OE Reports 180, SPIE Web, December 1998, wherein a mechanism for coating optical conduits such as fibers with aluminum using CVD as developed by Tohoku Univ. of Sendai, Japan; and “Delivery of F₂-excimer laser light by aluminum hollow fibers”; Matsuura, Y. et al; Optics Express Vol. 257, June 19, 2000, both incorporated herein by reference in their entirety.

It will be appreciated that other means of controlling and/or intensifying the laser energy or mode-coupling between fibers may be used consistent with the invention. For example, the use of glass dopants that induce laser energy amplification, reflection, or redirection may be employed within one or more fibers of the core, or within the material interposed in the interstices of the fibers. In one embodiment, the present invention envisages a fiber "bundle" such as that of Figs. 4 or 10 herein, with the interstitial regions being filled with a controllably varied chemical solution, the solution being used as a fuel, to control other properties, heat control, etc. The constituents of the solution may be varied as a function of time or other parameters to effectuate specific operational objectives, such as increased/decreased mode coupling between fibers, neutron reflection or absorption, gamma or X-ray absorption, fuel concentration, fuel injection rate, refraction of the mode-coupled energy, etc. Such a liquid control mechanism may also be circulated or selectively purged and replaced if desired.

For example, one variant of the invention uses a constant recirculation system wherein the volumetric density of interstitial "fluid" (which may also comprise at least part gaseous phase material) is controlled by selectively cooling or heating the fluid before introduction into the core. In this fashion, gamma, X-ray, neutron, and/or mode-coupled laser energy can be selectively moderated or reflected. In another embodiment, the interstitial fluid mix is varied on the fly, such as where the fuel concentration is increased to provide a higher core fuel density. Similarly, the pressure of the fluid can be controlled, thereby controlling the rate at which fuel is injected into the fibers via through-wall ports such as those described elsewhere herein.

It will also be appreciated that the foregoing liquid control scheme can be applied on a per-fiber basis if desired, such as where each fiber is surrounded at least partly by an annulus or chamber which can be separated from other fibers (or groups of fibers) of the core in general. Heterogeneous application of "control fluids" can be made across the core, much as different control rod positions and/or fuel densities are used in a conventional fission reactor to control the thermal and fast neutron longitudinal and radial flux profiles, so as to e.g., control power density and hence fuel burn rate. This approach allows for the balancing of the core power density, which may be required to control the thermal (temperature) profile across the core to prevent damage thereto (i.e., avoiding or mitigating "hot spots").

Similarly, as a logical extension thereof, the fuels concentrations and/or types can be varied on a per-fiber or per-group basis of desired in order to effectuate any of the foregoing objectives. For example, in those areas where leakage of mode-coupling energy is greater (such as at the periphery of the core), the fuel density and or laser pulse intensity can be varied to balance the core power profile and/or control temperature, etc. This fuel control can be accomplished by design (i.e., before operation), or “on the fly” using, e.g., the liquid or gaseous system previously described wherein fuel concentration, constituency, temperature, etc. can be varied as a function of time.

It will also be appreciated that mode-coupling between fibers can be selectively controlled, and can comprise uni-direction or bi-direction coupling. For example, with no control mechanism, mode-coupling can occur both in and out of a give fiber. However, through the selective application of polarizing materials or coating (or other approaches that limit the direction of wave propagation to one direction only), mode coupling can be made to occur predominantly only either into or out of a fiber, but not both.

Referring now to Fig. 5, an alternative embodiment of the fusion core of the present invention is shown and generally designated 300. The fusion core 300 includes a fiber 302 formed with a hollow core 304 and having an input end 306 and an output end 308. A fusion fuel 310, such as a deuterium fuel, may be coated or sprayed on the walls of fiber 302, or otherwise introduced such as via diffusion through the fiber walls. As yet another option, the fuel may comprise one or more elements (e.g., palladium wires) disposed centrally or in an array within the fiber lumen.

A radiation source approaches the fusion core 300 in a first direction 312, such as laser pulses 314, 316, and 318. As shown, these pulses may be focused in a taper angle 320 (shown in dashed lines) in order to focus concentrated radiation energy on input end 306. These pulses enter the input end 306 of the fiber 302 and provide optical energy 332 at an energy level sufficient to activate and react with the fusion fuel 310. As a result of this interaction, a fusion reaction occurs resulting in the formation of a plasma beam 334 exiting the output end 308 of the fiber 302.

The fusion core 300 may optionally be formed with an input shield 322 and an output shield 324 (shown in dashed lines). These shields 322 and 324 provide for the sealing of the fusion core to retain any fusion fuel therein. This is particularly useful in situations where the fusion fuel 310 is not a solid, such as when a powder, liquid, or vapor 311, is being used as the fusion fuel, and/or where it is desired to exclude exterior

environments (e.g., air) or contaminants from the interior of the fiber, such as where the core is at least initially maintained at a relative vacuum, or is purged with a gas such as nitrogen or argon. These shields are, in a preferred embodiment, made from a material that is optically transparent to the incoming radiation, although other configurations may be used depending on the desired properties.

In Fig. 5, the radiation energy that is mode-coupled into fiber 302 is shown with arrows 330. In this configuration, radiation energy is mode-coupled into the fiber 302 thereby increasing the energy level within the fiber to a level that is sufficient to initiate the fusion reaction with the fusion fuel 310. Also from this Figure, a tapering of the fiber 302 is shown thereby increasing the radiation energy level as the radiation propagates from the input end 306 to the output end 308.

The relative success of Ditmire's 1999 experiment at LLNL with laser fusion of deuterium, was in large part due to the use of fuel in the form of frozen deuterium clusters and not deuterium gas. These clusters contain D atoms in close proximity (approximately, 1 Angstrom). The short distances increase the probability that energetic D ions will fuse with adjacent ones. Each frozen cluster has thousands of atoms. Since each D-D fusion produces a characteristic energy neutron, the numbers of these neutrons detected indicate that 1-10 clusters took part in the initial Ditmire fusion ignition experiments.

The close proximity of D atoms in the fuel is an important consideration for the success of the fusion ignition process. In earlier experiments on inertial confinement, close proximity was achieved with a double pulse laser. The first pulse compresses the fuel with a powerful shock wave, and shortens the atomic distances. The second pulse accelerates the D ions into the now closer D atoms for the fusion ignition. This "double kick" is another avenue to achieving the necessary conditions for fusion.

However, frozen deuterium clusters may not be the best fuel. Specifically, they have to be produced by adiabatic expansion of deuterium gas into a vacuum, and if not used immediately, they are rapidly "thermalized" back into a gas. The small atomic clusters, and their small numbers within the focused laser beam, keep the critical ion density at low values. The short time associated with maximum laser intensity at the cluster positions, also reduces the critical confinement time. The hollow fiber approach of the present invention using fueled fibers containing D-Pd, increases both of these parameters significantly. More fusion fuel is incorporated, and a fiber-confined laser beam is used to maintain maximum laser intensity over a longer distance.

In the exemplary embodiment, a choice for a stable solid fuel is deuterated palladium (D-Pd), otherwise known as a "halide" or "deuteride". Palladium is a metal in the Platinum family, with an extraordinary propensity to absorb hydrogen and its heavy isotope deuterium. At maximum deuterium "loading", there are equal numbers of Pd and D atoms in the material. The palladium actually swells in size visually, as deuterium is added. Palladium is made into a negative cathode, and positively charged deuterium ions are made to strike it. X-ray measurements of the material show that the inter-deuterium distances are on the order of 1 Angstrom. In other words, they are very close to the inter-atomic deuterium distances present in frozen deuterium clusters. However, unlike frozen clusters, they are stable and can be used in air and at room temperatures. As will be recognized by those of ordinary skill, there are other deuterides that can be used similarly, including without limitation those of Ni, Li, Pt and Ti. The use of Li deuteride is particularly relevant, in light of its use in producing tritium fuel with neutron bombardment.

In one embodiment of the present invention, the palladium is sputtered onto the inside walls of the hollow fibers while they are a preform. The palladium is a ductile metal and can survive the drawing down of the glass fiber to fusion core dimensions, without detaching from the glass. In another embodiment, a vacuum or vapor deposition process of the type well known in the art is used to deposit the fuel onto the fiber walls.

It is also feasible to incorporate the palladium (or similar) into the fiber material itself during fabrication. Furthermore, it will be recognized that the palladium may be deposited or formed on the walls of the fiber in a heterogeneous fashion; i.e., mixed with one or more other substances such as Lithium, which may provide complementary or desired properties, such as increased adhesion during drawing down, neutron moderation/reflection/absorption, etc.

The process of loading deuterium into palladium can be accomplished by, e.g., ion bombardment. The palladium is made into a negative cathode and bombarded by positive charged deuterium ions while inside the fiber. Resistance measurements of the Pd can determine maximum loading. The maximum deuterium loading factors of Ni, Pt, and Ti, however, are less than palladium. However, it is envisaged that more efficient methods for deuterium or other isotope loading into palladium or other materials may exist or will be introduced over time, thereby further increasing the loading factors of these materials, the ion bombardment process being merely illustrative.

The propagation of femto-second laser pulses through the hollow core of the tapered D-Pd loaded fiber is initially shown in Fig. 5. Unlike the focused laser beam in air or vacuum shown in Fig. 1, the energy intensity of the present invention (irradiance in watts/cm²) actually increases as the laser pulses propagate down the fiber toward the output end 308. Irradiance increases due to, *inter alia*, the mode coupling of laser energy from adjacent fibers, self-focusing within the core plasma and the “focusing” action of the taper. With proper design, the pulse irradiance will reach $>10^{18}$ watts/cm² inside the fiber when the D-Pd fuel is reached by the wavefront(s), or when the deuterium clusters reached after they are introduced and/or sprayed into the fiber core through the wall ports.

Referring now to Fig. 6, an alternative embodiment of the fusion core of the present invention is shown and generally designated 400. The fusion core 400 includes a fiber body 402 with an internal fiber 403 formed with a hollow core 404. Adjacent fibers 405 and 407, having hollow core 406 and 408, respectively, are formed adjacent fiber 403. The fiber 403, in a preferred embodiment as discussed above in conjunction with Fig. 5, may be formed with a fusion fuel 410 coated on the inside surface of core 404.

Radiation energy 420 is directed toward the fusion core 400. In one embodiment, radiation energy may comprise radiation having several different wavelengths, or “broadband” radiation sources. For example, in Fig. 6, radiation energy 420 includes a first radiation source 422 having a first wavelength (81), a second radiation source 424 having a second wavelength (82), and a third radiation source 426 having a third wavelength (83). Alternatively, the spectral coherency of one or more of the lasers can be varied, such that a wider bandwidth of (less coherent) light is produced.

Radiation sources 422, 424, and 426 have been represented as a series of radiation pulses 428, 230, and 232 indicative of the femto-second laser pulses of one embodiment of the present invention. However, it is to be appreciated that the discussion of these radiation sources is merely exemplary, and the radiation sources may provide radiation which is continuous, all of the same wavelength, or a combination of continuous, pulsed, single or multi-wavelength radiation, either highly coherent or more spectrally distributed.

Radiation sources 422, 424, and 426 pass through the shield 434 and into the cores 406, 404 and 408, respectively. The radiation 424, which enters the core 404, interacts with fusion fuel 410 to create a fusion reaction and a resultant plasma/particle/EM beam 460 is formed which exits output shield 436.

Once the radiation is received within cores 406 and 408, this radiation begins its mode-coupling into core 404, as shown by arrows 450. Mode-coupling provides for the passage of radiation energy from cores 406 and 408, into fiber core 404 thereby increasing the radiation energy density within the fiber core where the fusion reaction will take place.

5 For example, by the introduction of additional radiation energy into core 404 through mode coupling as shown with arrows 450, a higher radiation level can be reached within the core 404. In fact, a radiation level that would otherwise be too great for the fiber to withstand if generated by a single ingress location can be achieved within the fiber core 404 with mode-coupling from adjacent fibers.

10 Optionally, one or more fuel ports 442 may be formed in the fiber 403 to allow the passage of additional fusion fuel from fibers 405 and 407 into fiber 403. More specifically, additional fusion fuel may be contained within the cores 406 and 408 of fibers 405 and 407 (or the interstices between the different fibers), and these fuels may be transferred into core 404 of fiber 403. As shown, the cores 404, 406 and 408 may have internal pressures P_1 , P_2 ,
15 and P_3 , respectively. When P_1 is less than P_2 and P_3 , fusion fuel within fiber cores 406 and 408 will pass through fuel ports 442 and into core 404 where the additional fusion fuel will be combined with fuel 410 in the fusion reaction.

The outer fibers 405 and 407 may be formed with external fuel inlets 438 to provide for the introduction of additional fusion fuel 440 into cores 406 and 408. In addition, these
20 fuel inlets 440 provide for the adjustment of the pressures P_2 and P_3 and the strength of the fusion reaction occurring in core 404. More specifically, by increasing pressures P_2 and P_3 , additional fusion fuel 444 will pass through fuel ports 442 into fiber core 404 to provide a stronger fusion reaction. Conversely, by decreasing pressures P_2 and P_3 , a decreased amount of fusion fuel 444, or perhaps no additional fuel, will be injected into core 404,
25 thereby decreasing the strength of the fusion reaction. Using this approach, a fusion reaction of a desired intensity may be created and controlled using the present invention. This pressure differential may also be used to control the egress of any vaporized or atomized fuel components or other materials outward from the core.

Varying degrees of field ionization will occur within the fiber's fusion fuel 410,
30 such as D-Pd coating and D_2 clusters along with "Wakefield acceleration" of D-ions, electrons, protons and other ions from the fusion and Pd. The electrons and ions are driven by, *inter alia*, the laser pondermotive force in the direction of the laser, or radiation source 420, down the fiber, and into further interactions with additional D-Pd and D_2 fuel. The

pondermotive force (photon pressure) acts much like a "snow plow", forcing the plasma and other constituents ahead of the wavefront down the fiber length, with the laser pulse performing relativistic "self-focusing" within the plasma (thereby increasing the tight collimation in the direction of the laser pulses). See, e.g., "Amazing Power of the Petawatt",
5 K. Walter (citing Michael Perry, Lawrence Livermore National Laboratory), Science and Technology Review, 2000, which is incorporated herein by reference in its entirety. See also "Laser-Like Beam May Break Barriers to Technological Progress", NSF Press Release 02-60 dated July 18, 2002 (citing work at the Univ. of Colorado referenced above), incorporated herein by reference in its entirety, wherein an EUV beam is generated that can
10 produce a very small diameter high-energy laser-like beam (i.e., several times smaller than a more common helium-neon laser and several hundred times more intense).

The fusion process within the present invention can be described as a "cascade" fusion ignition of the deuterium fuel on the inside of the fiber 403. This reaction can be further enhanced with the addition of additional D clusters or other fuel coming through
15 other porous sections of the tapered glass fiber 403. It will also be recognized that heterogenous types of fuel can be used, such as where different portions of the fiber interior are coated with different types of fuel, and/or "downstream" injection of a fuel different from that upstream on the fiber walls (or injected upstream) is used.

At all points in the interaction, a strong radiation field is present. For relativistic
20 plasma moving down a fiber, the laser pulse remains in close proximity to the plasma. This is in contrast to previous cluster ignition methods, in which a reaction occurs in only a small laser focus region, measured in microns. Advantageously, the propagating laser field 420 (and associated EM fields) acts to cause further ionization, and help confine the plasma into a ring or shaped region within the fiber core 404 and away from the glass walls, the
25 plasma moving in the laser direction 424.

In a preferred embodiment, the laser radiation will self-focus substantially along the axis 470 of the fiber 404 and propagate along a central axis of ions, forming a core (or ring) of high energy, relativistic plasma that exits the fiber at its effluent channel, as shown in Figs. 5 and 6. Rather than hit the interior walls of the glass fiber 403, the plasma 460 will
30 be highly collimated with the laser energy, and remain within the lumen, or core 404, of the fiber. Transverse plasma motion and photon motion (and to some degree neutron emission) is expected to be smaller.

In the fusion core of the present embodiment, the ion density within the core 404 is determined primarily by the entire amount of fusion fuel material, such as D-Pd and D₂, inside the fiber 403. Likewise, the confinement time is determined by the laser transit of the entire length of fusion fuel 410, such as deuterium, in the fiber 403, which can be many millimeters, and even centimeters or longer in length. The Lawson factor is therefore increased by a significant amount.

Referring again to Fig. 6, it is to be appreciated that the additional deuterium fuel in the form of frozen clusters, gas and even liquid, can enter the lumen, or hollow core 404 of the tapered fiber 403 through porosity and holes 442 formed in the walls of the various glass fibers. Porous glass, such as "Vycor" is commercially available, and/or sub-micron holes can be drilled in the fiber walls with lasers using a method that is known in the art. The walls of the fiber can also be impregnated with fuel atoms at or after manufacture such that these atoms are given up to the lumen as the temperature of the fiber wall is increased.

Furthermore, many kinds of glass can become porous to Hydrogen (including Deuterium) by simply heating the glass to temperatures between 400 degrees F and 700 degrees F. It is anticipated that the fusion reactions inside the hollow lumen of the glass fiber, will provide enough heat to raise the glass temperature to well above 400 degrees F and permit outside pressurized deuterium fuel to diffuse into the fusion reaction area.

The use of porous glass to allow "fueling" of the fusion reaction is illustrated in Fig. 6. The pressurized deuterium gas may be located within, or introduced into, the larger adjacent fibers 405 and 407, and enters the smaller D-Pd loaded fibers adiabatically, through the fuel ports 442 as a "spritz" of fuel, e.g., frozen deuterium clusters.

The apparatus of the present embodiment permits the fusion reactions within core 404 to be continuously fueled with fusion fuel such as deuterium, and power controlled by the amount of fuel allowed to enter the fibers through the fuel ports 442. It is further envisaged that the fusion reactions can run totally with the spritz of (frozen) deuterium or other fuel, and without the Pd-D coating on the lumen walls. With larger walls, deuterium can enter as a gas or even a liquid spray of heavy water, or via other mechanisms that will be readily apparent to those of ordinary skill provided the present disclosure.

It is further recognized that the fuel may even comprise plain (i.e., non-heavy) water, and ordinary hydrogen fusion will take place albeit with a smaller fusion cross-section than for deuterium. Under the intense radiation associated with the fiber and fuel

chambers, substantial dissociation of heavy water molecules will occur, thereby forming quantities of deuterium which can then act as the fusion fuel for the core.

In another embodiment, the fuel introduction system comprises atomized or particulate form (such as a spray or stream of deuterium or a liquid solution such as atoms
5 disposed within water) which is prayed or otherwise injected into the fiber from the ingress end just ahead of the laser pulse, such that the pondermotive force pushes or “plows” the fuel atoms into the fiber lumen.

The hollow glass fibers of the present invention may also be used in laser fusion geometries other than a “linear” geometry as previously illustrated. The fundamental
10 concept is that glass fibers, including e.g., the holey fibers previously described, act as wave guides for laser light or other EMR that can redirect the light into any direction by bending the fiber; and the light pressure can then force atoms, ions and particles to also undergo a change in path direction to follow the light. The shape of the fiber containing fusion plasma and laser pulses therefore advantageously becomes arbitrary. In fact, modern designs of the
15 holey fibers have demonstrated the bending of light around 90 degree turns in an area of a few hundred square microns, thereby allowing for significant “kinks” or discontinuities in the fiber to be present if desired or required for some other design objective.

Referring now to Fig. 7, another variant of the fusion core of the present invention is shown and generally designated 500. The fusion core 500 includes a holey fiber 502 having
20 an input end 504 and an output end 506 and formed with a lumen or hollow core 508. A radiation source, such as laser input 510 is directed at the input 504 and propagates down the hollow core 508 until striking the fusion fuel 512 positioned therein. The fusion fuel 512 is shown as a solid and positioned against the wall of lumen 508; however, it is to be appreciated that any type of fusion fuel may be contained within fiber 502, including fluid,
25 gas, vapor, powder, or a combination thereof. The input end 504 and output end 506 may be formed with seals shown in dashed lines to, *inter alia*, retain any fusion fuel within the hollow core 508 of the fiber 502. As radiation 510 enters the hollow core 508, a fusion reaction occurs and creates a plasma beam 514 which exits the output end 506.

The fusion core 500 of the present invention may optionally be equipped with a
30 source of electrical energy generally designated 516. The energy source 516 includes, for example, a current source connected to windings placed about the fiber 502. In this configuration, the current source provides a current within windings that correspondingly create a magnetic field within the fiber 502, the field increasing the energy level within the

core 508. Depending on the orientation of the windings, the magnetic (B) field vector(s) can be generated in any desired direction, including longitudinally along the central axis of the fiber, or transverse thereto.

Depending on the longitudinal position of the windings, the external magnetic field can also be used as a “steering” device for charged particles within the fiber, since charged particles moving in a magnetic field will feel a force in the direction of the vector cross product of the charge velocity and the B-field, as is well known.

Further, the addition of a magnetic field within core 508 can be used to maintain the formation of a central plasma beam separated from the inside of fiber 502.

Referring now to Fig. 8, an alternative embodiment of the present invention is shown to illustrate the flexibility of the fusion core geometry. More specifically, fusion core 550 includes a fiber 552 containing a fusion fuel (not shown this Figure), and having an input end 554, and an output end 556. Radiation enters the input end 554 and reacts with the fusion fuel to create a plasma beam 562 which leaves the output end 56. Of interest in this Figure, however, is that the fiber 502 is shown as non-linear. In fact, the fusion core of the present invention is capable of other shapes other than linear, and that the presentation of the embodiment of Fig. 8 is merely exemplary of the versatility of the present invention, and no limitations as to available configuration is to be inferred. As will be described subsequently herein, myriad different core shapes are possible, including for example arced, circular, helical, elliptical, oval, or conic (or frustoconic).

In another alternative embodiment of the present invention, a fusion core may be formed with a fiber having a central hollow fiber surrounded by an array of hollow fibers having significantly smaller diameters. Generic holey fibers are created in this manner. Referring to Fig. 9, such a fusion core is shown and generally designated 600. The fusion core 600 includes a fiber 602 formed with a central lumen, or hollow core, 604, and formed with a plurality of additional hollow cores 606 having diameters which are substantially smaller than the central hollow core 604. The fiber material 608, such as glass, provides for an optically transmissive media between the various hollow cores 604 and 606 such that radiation received in the hollow cores 606 mode-couple into the central core 604 thereby increasing the radiation level within that core. The interstices between the fibers may also be selectively evacuated if desired such as to permit diffusion of atomized, gaseous or liquid fuel (including the aforementioned carbon nanostructures) into the central region 604, to provide neutron reflection, etc.

In another embodiment of the invention, the fibers (or core "block") can be coated, such as on their inner or outer surfaces, and/or doped with a neutron reflective material such as graphite, beryllium, or even heavy water (e.g., Deuterium Oxide) to reflect neutrons back into the hollow core region to induce additional reactions (such as with Lithium-6).

5 Advantageously, in one configuration, the additional fusible fuel introduced in the fiber hollow core via fiber wall porosity or holes is also used as the neutron reflector. A constant annular "thickness" of deuterium-based fusible fuel present around the outer surface of the fiber acts as both a fuel source and a neutron reflector. This configuration also has control ramifications; i.e., in the self-sustaining (non-pumped) mode of operation, expiration of the
10 external fuel source coincides with degradation of the neutron reflection coefficient of the apparatus, thereby in effect allowing further energy to bleed from the hollow core. Stated simply, when the external fuel runs out, so does the neutron reflectivity, thereby resulting in a self-initiating shutdown. Alternatively, the density or thickness of the reflector material may be used as a control mechanism.

15 In another exemplary embodiment, selectively movable neutron reflecting elements (akin to control rods in a fission system) are used to allow control of the neutron reflection characteristics of the core as a whole, or for individual core fibers or groups of fibers. Mechanism for providing such control are readily fashioned by those of ordinary skill, and accordingly are not described further herein.

20 Fig. 10 presents another alternative embodiment of the fusion core of the present invention and is generally designated 650. The fusion core 650 of Fig. 10 includes multiple fibers 602 (of the type shown in Fig. 9), and grouped together to form a bundle. The fibers 602 are attached or formed together using an optically transmissive material, such as glass 652, although other materials may be used as desired. In this configuration, the radiation
25 energy levels within fiber cores 604 will increase due to the radiation mode-coupled from adjacent fibers 602. As with the embodiment of Fig. 9, the interstices of the bundle can be used to control mode coupling, store and/or introduce additional fuel, provide cooling to the fibers (and draw away thermal energy), act as a neutron/energy reflector, or provide various other functions.

30 Referring now to Fig. 11, another alternative embodiment of the fusion core of the present invention is shown and generally designated 700. The fusion core 700 includes a fiber 702 having a central lumen or hollow core 704. The central hollow core 704 is axially surrounded with a sleeve 706 of optical fiber material, such as glass or quartz, having a first

index of refraction. A second sleeve 708 of optical fiber material, such as glass, having a second index of refraction axially encases the first sleeve 706. Similarly, a third sleeve 710 of optical fiber material, such as glass, having a third index of refraction axially encases the second sleeve 708. Finally, a fourth sleeve 712 of optical fiber material axially encases the third sleeve 710. It will be appreciated that more or less layers or sleeves may be used, the present configuration being merely illustrative.

By choosing the indices of refraction appropriately, it is possible that radiation striking the input end 713 of fiber 702 is focused inward toward the center 704 of the core. As is known, the interface of two materials of varying index of refraction will produce a bend or change in direction of propagation via Snell's law. Hence, by choosing materials with progressively larger or smaller indices of refraction, the incident light energy coupled into the various layers can be selectively "focused" or dissipated, respectively, the light changing direction inward (radially) or outward at each interface between sleeves.

Furthermore, the use of various materials having different indices of refraction allows for multiple propagation modes within the fiber. This approach may be desirable where temporal distortion or chromatic dispersion of the laser pulses as they propagate down the fiber can be tolerated.

The fiber 702 of fusion core 700 may be formed with a number of fuel input ports 714 for the introduction of fusion fuel into hollow core 704 as discussed above in conjunction with Fig. 6. It will be appreciated that while Fig. 11 illustrates a single row of circumferentially disposed ports, literally any formation or combination of ports can be used, including for example being disposed in a plurality of circumferential rings down at least a portion of the length of the fiber, being disposed in one or more linear arrays down the length of the fiber, being disposed according to a geometric parameter (i.e., the ports increasing or decreasing in diameter as a function of position, arc, etc.), or being configured so as to be selectively permeable under different physical conditions. Myriad other configurations will be recognized by those of ordinary skill. Means for controlling the introduction of fuel into the containment fiber(s) are well known in the mechanical arts, and accordingly not described further herein.

It will also be recognized that the fiber wall holes and porosity used to admit fuel can serve another important function, which is to cool the hot fibers. Heated fibers will cause the liquid (e.g., water) fuel to boil and form vapor, which not only enters the hollow fiber core as a fuel, but also lowers the glass temperature. Hence, in one exemplary

embodiment, the fiber is surrounded by one or more channels (to include even a concentric fiber or other chamber of larger radius). Fuel (e.g., liquid, gas, etc.) is contained in the channel(s) such that it is in communication with the outer surface of the fusion core fiber. As the fiber is heated by the ongoing fusion within the fiber lumen, heat is transferred to the liquid or gas, thereby increasing its pressure within the closed constant-volume channel(s). As pressure builds, more of the liquid or gas fuel is diffused into the porous fiber wall, thereby inserting more fuel into the fiber lumen. The porosity of the fiber can also be controlled or selected such that only vapor phase fuel can be passed through the fiber wall, in effect using a fuel "boiler" akin to a steam generator in the secondary plant of a conventional fission PWR.

In light of the fiber's ability to steer the optical radiation and resultant plasma beam as previously described herein, the embodiment shown in Fig. 12 includes one or more hollow fiber fusion cores of glass or other material (to include the multi-sleeved variant of Fig. 11 if desired) that have the shape of a toroid (closed circle) with ports to allow laser light to enter and fusion plasma to exit. This apparatus of Fig. 12 presents a "re-circulation" technique, similar to the prior art Tokamak, which greatly increases the ion particle density inside the fiber lumen, and greatly increases the containment time, both critical components in the Lawson criteria. However, a salient distinction between the prior art Tokamak device and the fiber fusion core of the present invention is that the fiber fusion core (including even the femto-second laser) will fit onto a table top, while the Tokamak requires a building-size structure.

Rather than supply outside magnetic fields to force the plasma particles into circular and re-circulant paths as in the Tokamak, the laser photon electromagnetic fields generated by the present invention provide the necessary pondermotive force to keep the plasma contained within the fiber lumen and hence propagating in a circle trajectory. Fusion fuel can be continuously or intermittently fed into the circular fiber trough the porosity of the glass, and mode coupling occurring at the laser injection port(s) continuously transfers new laser pulses into the circular fusion fiber core. Hence, the apparatus of Fig. 12 can be operated for relatively lengthy durations, up to even continuous operation under the proper conditions. In order to support long-term operation, other facilities may be required, however, including a cooling medium to dissipate thermal heat of the fiber which may become deleterious to the fiber material or other components after a few seconds of sustained operation.

Another salient benefit of the fiber fusion core of the present invention is the retention of a substantial fraction of the radiation generated from accelerated plasma charges within the core of the fiber and the fusion process in general. As is known, a wide variety of subatomic species (e.g., neutron, protons, electrons, neutrinos, and even fractional or elemental particles such as quarks) and electromagnetic radiation (including e.g., X-rays, gamma rays, UV, visible light, etc.) can be emitted from a fusion event under proper circumstances. The pondermotive forces generated by the traveling laser wavefront(s) and associated magnetic fields in effect form a containment "sleeve" inside the fiber, tending to deflect any escape of these species and EMR. Certain particles such as neutrinos will be largely unaffected by the pondermotive sleeve; as will (albeit to a lesser degree) neutrons. While no practical neutrino deflection or reflection apparatus can be applied, various schemes and materials which reflect neutrons ranging from thermal to fast energy can be used, as described in greater detail subsequently herein. The formation of the sleeve, with or without the neutron reflector, greatly enhances the energy density within the fiber. In a typical Tokamak reactor, the radiated photon energy (and a portion of the neutron energy) is substantially lost.

Radiated light (e.g., Bremsstrahlung or braking radiation) from accelerated plasma charges in the core are also confined to the core by the single mode holey fibers and not lost as in the prior art Tokamak. Rather, they add their pondermotive forces to that of the introduced laser pulses, and under certain circumstances may sustain the plasma reactions with the laser turned off (at least intermittently). The amount of this radiated light increases dramatically as the Z^4 value of the ion species in the plasma, and can be a significant part of the radiation field within the fiber.

A significant fraction of the uncharged particles emanated from the various reactions occurring within the core (such as the neutron) will be held in fiber confinement via the mechanisms of a) photon pondermotive forces (photon pressure), b) reflection off the interior walls of the fiber core, and c) collisions with other particles such as electrons and protons moving axially down the fiber core (i.e., conservation of linear momentum and energy). Use of neutron reflectors (such as described elsewhere herein) further increases the fraction of neutrons emitted from the fiber effluent.

The relative spatial efficiency of the fiber core for neutron ejection (flux) within the effluent solid angle Φ can be related to the total neutron flux created within the core:

$$\eta = N_e/N_t \quad \text{Eqn. (7)}$$

where:

η = Efficiency

N_e = Total No. of neutrons (all energies) emitted within solid angle Φ

N_T = Total No. of neutrons (all energies) emitted within solid angle 4π

- 5 The efficiency η represents simply a measure of how many neutrons are emitted with the desired effluent solid angle as compared to the total number emitted over all solid angles within the same time period. The greater the efficiency, the smaller the leakage of neutrons through the walls of the fiber, the other end of the fiber core, etc. It will be appreciated that simply by virtue of the physics of the fusion process disclosed herein, including the
- 10 directionality of the incident laser energy, the fiber geometry, presence of pondermotive forces, etc., certain solid angles are preferred (i.e., have higher probabilities of neutrons being ejected within those angles with all else being equal). Hence, in the linear fiber/core geometry previously described herein, the solid angle centered on-axis in the downstream (effluent) direction would naturally have the highest neutron flux density, whereas the opposing solid
- 15 angle ("upstream") may have the lowest flux due to e.g., pondermotive forces. Hence, optimal or highest efficiency for such a geometry will always be achieved when the solid angle is chosen on-axis in the downstream direction.

Use of a neutron reflector increases η , since more neutrons are reflected back into the lumen of the fiber where they can interact with other particles, or be re-subjected to photon pressure. Such reflections also have a finite probability of direct reflection into the solid angle Φ .

20

Similar to the neutron reflector, increased pondermotive force provides a greater "restraint" or photon pressure on the neutrons, thereby lessening their lateral escape probability. Hence, as the power density of the exciting laser or EMR pulse increases, so does

25 the pondermotive force, thereby reducing the fraction of neutrons "lost" out the fiber walls.

It will also be appreciated that varying levels of interaction between the charged particles within the lumen may occur, such as where high speed particles will exert an electrostatic force on other charged particles. However, the combination of the conserved momentum within the lumen, intense pondermotive forces, and other forces (such as any

30 externally applied "helper" or containment fields) will be sufficient to cause the great preponderance of charged particles to also be ejected out through the solid angle of interest (i.e., out the effluent end of the fiber lumen).

Referring more specifically to Fig. 12, an alternative embodiment of the fusion core of the present invention is shown and generally designated 800. The fusion core 800 includes a circularly shaped optical fiber 802 having an input port 804 for injecting radiation 806, and an output port 808 for ejecting plasma 810 and effluent. As will be
5 discussed in greater detail below, radiation 806 enters the input port 804, circulates through optical fiber 802 in direction 812, and exits at the output port 808 as a plasma beam 810.

The fiber 802 of the illustrated embodiment is formed with a series of fuel inlets 814 which allow fusion fuel 816 to pass from a region of higher pressure P_1 to a region of lower pressure P_2 within the hollow core of fiber 802. This pressure gradient between P_1 and P_2
10 may be adjusted to control the volume of fusion fuel which enters fiber 802.

An output switch 820 (shown in dashed lines) may be used to perturb the plasma beam circulating through fiber 802 in order for all or part of the beam to be diverted to output port 808. The output switch 820 includes a diverting laser beam 822 which is at an angle 824 to the fiber 802. In a preferred embodiment, this angle 824 is 90 degrees, but in
15 other embodiments, this angle may vary depending upon the size of the fiber, the curvature of the fiber, and the radiation intensity or plasma energy level within the core 802 (as well as the intensity of the diverting beam 822). Each of these factors may determine the positioning of diverting laser beam 822.

The diverting laser beam 822 effectively exerts a lateral pondermotive force or
20 pressure on the existing plasma within the fiber, in effect causing acceleration toward the output port 808. The Lorentz force ($v \times B$) from laser 822 causes the plasma to drift outward to the port 808.

The beam 822 can be operated intermittently, such as where the beam intensity ramps (one or more pulses) rapidly so as to effectively push a "slice" of the circulating
25 plasma out the port beamline until the constriction collapses and the plasma is again contained within the fiber. A secondary pondermotive or magnetic field can be created in the beamline port itself to further guide the ejected plasma out the port without significant interaction with the walls of the ejection port fiber. It will be recognized, however, that the ports need not be linear as shown, and in fact may comprise simply an extension of the
30 circular (primary) path of the core. For example, consider the case where a curved portion of fiber having a radius substantially identical to the primary fiber path is used.

It will also be recognized that other mechanism or techniques may be used to provide the output port switching function. For example, an intensified magnetic field can

be created at the location of the open port in a direction and gradient such that the pondermotive forces are substantially maintained at that point of the fiber. Only when the field collapses does the port “open” such the pondermotive field is at least partially weakened in the region of the port, and a portion of the circulating plasma stream is diverted out the port. Similarly, an external magnetic field of sufficient strength can be used to deflect the path of at least the charged particles to a desired trajectory.

As yet another alternative, a “bucking” pondermotive field (such as created by a laser pulse propagating in the reverse direction) can be used to selectively destroy the pondermotive containment field at one or more locations within the fiber, thereby allowing a radial excursion of plasma and other species (such as through a circumferential “grating” formed at one or more locations in the fiber wall).

The cascade fusion ignition of the present invention is somewhat of a combination of inertial confinement, similar to cluster ignition, and laser confinement. The laser’s pondermotive force both drives the plasma down the core and shapes it and confines it. It is another example of what has become known as “atom optics”, or the guiding of atoms by light.

The aforementioned pondermotive force or photon pressure is due to the Lorentz force of the photon’s electromagnetic field (e.g. $F=qE+qV \times B$). At relativistic speeds, this relationship is more accurately represented as in Eqn. (8):

$$F = \frac{d(\gamma p)}{dt} = eE + e \left(\frac{v}{c} \times B \right)$$

Eqn . (8)

In a real sense, the photon pressure is another example of magnetic confinement due to the $qV \times B$ term. The difference, however, is in the size of the magnetic fields. The localized photon magnetic field of the laser has been estimated by hydrogen line broadening techniques to exceed 10 MGauss. This is significantly larger than the 20-30 kGauss fields produced in a typical Tokamak. While the present invention can be adapted to larger scale architectures, small size actually aids in the creation of such intense magnetic fields, since the high power density of the incident laser(s) is coupled into and confined within a very small space. Stated simply, it is much easier to create a Mega-Gauss-level magnetic field in a small fiber volume than a larger containment such as a Tokamak torus.

Similarly, as laser power densities increase to 10^{20} watts/cm² and higher, the pondermotive photon forces associated with such power densities allow plasma confinement in smaller and smaller architectures including, e.g., the “recirculating”

architecture of Fig. 12. These small architectures are even amenable to manufacture using integrated circuit fabrication technology. Accordingly, while the illustrated embodiments are rendered primarily in terms of "table top" or comparatively larger sized devices, it is envisaged that improvements in the extant technologies and processes over time will allow
5 reduction of the size of the core (and entire apparatus) of the present invention to very small size, even so as to be contained within a single or hybridized "SoC" type integrated circuit package. Specifically, the holey fiber structures may be rendered at a micro scale, such as being etched in one or more layers or structures of glass, silicon, silica, diamond, carbon and other materials.

10 In such an integrated circuit device, the fusion apparatus may also contain its own integrated fuel source of hydrogen, deuterium, etc. For example, the Hydrogen or Deuterium fuel can be stored within the hollow fibers by diffusing the gases through the glass fiber walls at elevated temperatures (approx. 200-300 degrees C) and releasing the stored gas by using elevated temperatures again (laser activated process). Internal pressures
15 of stored gases in silica fibers can exceed 8000 PSI. As previously discussed, certain materials (e.g., glass such as Kodak's Vycor brand) allow water vapor to diffuse through the glass walls, thereby acting as a fuel delivery mechanism. The hydrogen (including minute deuterium and tritium concentrations) intrinsically present in water vapor can be used to provide the fuel, or alternatively the vapor can be enriched with the heavier isotopes or even
20 other fuels (such as, e.g., Lithium). Alternatively, the fuel can be impregnated into the walls of the minute fiber(s) (such as at high temperature), and then released into the lumen by again heating the fiber walls as previously described.

Referring now to Fig. 13, and alternative embodiment of the fusion core of the present invention is shown and generally designated 900. The fusion core 900 of this
25 embodiment includes a fiber 902 formed with multiple radiation inlet ports 904A-H for receiving radiation 906A-H. The inlet ports 904 are mode-coupling devices for coupling radiation into the fiber 902. This radiation, once coupled into fiber 902, is circulated in a given direction 910 and reacts with fusion fuel introduced through fuel inlet ports 918 until the plasma beam 113 exits output port(s) 914.

30 Ejection of the plasma 913 from the fiber 902 is the result of output plasma switch 920. The output switch 920 is equipped with, e.g., a perturbing laser 922 for introducing energy into the plasma beam to redirect the plasma 913 out exit port 914 as previously

described herein with respect to Fig. 12. The output switch 920 can alternatively comprise magnetic fields which are adapted to switch the plasma out via the port(s) 914.

In the recirculating architectures of Figs. 12-13, the recirculating plasma inside the hollow fibers will have axial velocities on the order of 0.9 the speed of light, and consist mostly of light particles including electrons, protons, neutrons, positrons and the charged nuclei of light elements such as oxygen and nitrogen. The recirculating architectures, with one or more exit "portals" akin to the beamline ports of the well known synchrotron ring, can be used for any number of purposes including without limitation research or ion implantation into materials. It will also be recognized that the ejected ions, etc. carry with them momentum ($p = mv$), thereby inducing a reaction force according to conservation principles. Hence the present invention can be configured as an ion-propulsion engine. One application of such a technology is as an engine for space vehicles.

Similarly, plasma inside the hollow fiber(s), whether in the linear or recirculating architecture or otherwise, can also be configured to act as a plasma/ion weapon for military or other uses. Specifically, a relativistic beam of neutrons, ions, electrons, etc. would have great lethality against biological entities as well as non-living materials (e.g., penetration of shielded warheads or other components such as tank armor, buildings, aircraft components, etc.)

It will also be appreciated that the recirculating architectures disclosed herein can be configured with one or multiple unconnected or connected loops, the latter used to increase the volume of plasma and allow a longer laser/plasma interaction path for greater extraction of laser energy. For example, it is envisaged that a helix of many turns having a radius on the order of a few centimeters can be fashioned to provide an effective fiber length of many hundreds of meters or even kilometers. Furthermore, the laser energy can be introduced at multiple points along the path of recirculation, as shown in the exemplary configuration of Fig. 13 wherein energy is inserted at two or more portals disposed along the periphery of the loop(s).

In yet another variant (Fig. 13A), the fiber coil(s) of the core can be disposed in a helical fashion (including those with variations in the radius and/or spacing between turns) or others so as to capture neutron, EMR and other energy emitted within certain solid angles, in effect "reusing" within other portions of fiber. Specifically, the neutrons/energy emitted within the interior solid angles of each fiber turn will intersect other fiber turns disposed opposite of the emitting turns, the emitted energy being absorbed by the fuel

within the other turns, thereby increasing the energy in that region of the fiber. Similarly, dual or multiple concentric helices (same lay or inverse) may be used (Fig. 13B), or interlocked non-concentric helices with the same lay (Fig. 13C). The helical or coiled fiber may also comprise a plurality of bundled fibers such as shown in Figs. 9 and 10 herein, which may be in a straight, spiral or even braided geometry if desired. Myriad other geometries which provide for energy "reuse" as described herein will be appreciated by those of ordinary skill. These geometries can also be adapted to include one or more laser insertion ports and ejection ports as shown in Figs. 12 and 13.

Additionally, neutron reflective material can be added selectively outside of the helix to reflect energy inward. Individual turns of the fiber(s) can also be coated individually (whether internally or externally) if desired, such as with Beryllium, Deuterium Oxide (D_2O), or $^{58}Ni/Mo$.

In yet another embodiment of the invention shown in Fig. 13D, an exemplary collider apparatus is provided. Specifically, two or more of the recirculating architectures of Figs. 12 and 13 are disposed in mirror-image to one another, with their ejection beam ports positioned to cause collisions between the plasma effluent of the ports, either directly or at an oblique angle. As can be appreciated, the collision of ejected plasma at near relativistic speeds can be used to produce certain types of elemental particles and species, or for other purposes. The collision chamber 950 of Fig. 13D can be instrumented to detect these species, as well as shield against emissions from the chamber. As shown in Fig. 13E, multiple loops can be used in a two-dimensional (e.g., hexagonal) or even three-dimensional (e.g., spherical or truncated icosahedron) configuration to provide increased plasma density within the chamber.

Referring to Fig. 14, a cross-section of yet another alternative embodiment of the fusion core of the present invention is shown and generally designated 1000. This fusion core 1000 includes a fiber 1002 formed with a hollow core 1004 and having an inlet seal 1006 and an output seal 1008 to define a fuel chamber 1010 within the fiber 1002 between the input seal 1006 and the output seal 1008.

A fusion fuel 1012 may be positioned within fuel chamber 1010, and may in a preferred embodiment comprise a solid fuel coated on the inside surface 1011 of hollow core 1004. A fuel vapor 1014 may also be contained within fuel chamber 1010 and retained within fuel chamber 1010 by seals 1006 and 1008. A solid fuel pellet 1016 may also be

positioned on the input seal 1006, and a fusion fuel 1018 material may also be positioned on the output seal 1008. One or more of these approaches can be used as desired.

5 The fusion core 1000 of the present embodiment is capable of being charged with fusion fuel, and then stored or maintained for some time prior to creation of the fusion reaction. Herein lies a significant advantage over "frozen cluster" or other transient approaches. More specifically, the fiber 1002 may be charged with one or more of the fusion fuels 1012, 1014, 1016, or 1018 and then sealed with input seal 1006 and output seal 1008 (and optionally evacuated of air or filled with a purge gas). Once sealed, the fusion core 1000 may be stored for a period of time for future use. Any number of sealing
10 materials may be used, including for example glass, quartz, or polymers (such as polyethylene). Solidified fuel itself may even be used for the output seal 1008.

When a fusion reaction is desired, fusion core 1000 may be removed from storage and exposed to a radiation source, such as a laser. This radiation source enters fusion core 1000 in direction 1019 and strikes input seal 1006 which may be transparent or translucent
15 to the incoming radiation, or it may be opaque to the incoming radiation. In the event the input seal is translucent or transparent to the incoming radiation, the radiation passes substantially through the seal 1006 and strikes the fusion fuel 1012, 1014, 1016 and/or 1018 to create a fusion reaction and form a plasma beam 1020. Plasma beam 1020 strikes and obliterates output seal 1008 and exits as plasma 1022.

20 In circumstances where input seal 1006 is opaque to the incoming radiation, the seal 1006 is obliterated by the incoming radiation thereby allowing the radiation to strike fusion fuel 1012, 1014, 1016, and/or 1018 contained within fuel chamber 1010. Radiation striking the fusion fuel creates a fusion reaction which in turn generates a plasma beam 1020 that passes through output seal 1008 as plasma 1022.

25 In an alternative embodiment of the fusion core, a radiation source 1026 may be provided. More specifically, radiation source 1026, such as a laser diode or other known or discovered radiation source, may be positioned at least partly within the fiber 1002. Laser diodes are well known to those of ordinary skill in the art, and accordingly are not described further herein. When a fusion reaction is desired, a power source, such as battery 128 may
30 be attached or connected to the radiation source 1026 to generate the radiation energy necessary to initiate a fusion reaction. This embodiment of the present invention provides for a substantially self-contained fusion plasma generator. It will also be recognized that

the fiber 1002 can be elongated as necessary to provide the desired level energy concentration and fusing to occur.

In that the aforementioned cores 1000 are substantially self contained (even without the laser diode or other indigenous source), they can be used much as any other self-contained expendable commodity. For example, a revolver-type rotary structure (not shown) can be used with the cores, such that after each core 1000 is expended, a new core 1000 is rotated into a "barrel" so as to be aligned with the (stationary) pumping laser source. Alternatively, the cores 1000 can be fed magazine-style through the aforementioned apparatus and ejected after they are expended (akin to a linear prior art machine-gun or rifle clip). A multi-barrel rotary structure may also be used to increase the energy output per unit time, akin to the well known Gatling gun or more modern Vulcan rotary cannon. It will be appreciated that with recent and projected advancements in femto-second laser technology as well as holey-fiber fabrication, the foregoing devices could conceivably be reduced to a rifle-size or even hand-held device, the effluent plasma, particles and EMR providing a formidable weapon or cutting tool or the like. This is particularly true where the cores 1000 are coupled with the recirculating geometry of Figs. 12 or 13, the latter allowing for increased energy density of the effluent.

In yet another embodiment, the cores 1000 can be cascaded or disposed in series such that plasma and effluent emanating from one core 1000 acts as the input to a subsequent core 1000.

Referring to Fig. 15, still another alternative embodiment of the fusion core of the present invention is shown and generally designated 1100. In this configuration, the fusion core 1100 includes a main fiber 1102 formed with a hollow core, or lumen, 1104 and having a plurality of "feeder" input fibers 1106, 1108, 1110 and 1112 for receiving radiation 1114, 1116, 1118 and 1120, respectively. As shown in this Figure, the first radiation 1114 has an intensity I_1 , the second radiation 1116 has an intensity I_2 , the third radiation 1118 has an intensity I_3 , and the fourth radiation 1120 has an intensity I_4 . Each input fiber 1106, 1108, 1110, and 1112 is formed with a hollow core 1122 such that radiation 1114, 1116, 1118, and 1120 enter core 1104 of fiber 1102 to form a composite radiation 1124. The composite radiation 1124 has an intensity roughly equivalent to the sum of the intensities of the constituent radiation 1114, 1116, 1118, and 1120, and reacts with fusion fuel 1126 within core 1104 to create a fusion reaction and generate a plasma beam 1130. It will be appreciated that while a substantially two-dimensional configuration

is shown in Fig. 15, other configurations may be used, such as where an equal or greater number of constituent fibers are disposed in radial or circumferential fashion around the periphery of the central core fiber 1012. As another alternative, a number of smaller diameter straight fibers are placed in parallel bundled disposition at the ingress of a larger diameter “collector” fiber having diameter roughly equivalent to that of the bundle.

In an alternative embodiment, additional fusion fuel 1134 may be added to core 1104 of Fig. 15 through one or more fuel ports 1132 (shown in dashed lines). Such fuel ports 1132 provide for the addition of any fusion fuel thereby further enhancing the fusion reaction within fiber 1102. This port 1132 may also be used in conjunction with the other fuel introduction mechanisms previously described herein (e.g., ports through the fiber wall, diffusion, embedded fuels released at elevated temperature, etc.) if desired.

Figs. 16A-D provide end-views of various alternative embodiments of optical fibers being used in the present invention. More specifically, Fig. 16A depicts a fiber designated 150 having an oval cross-section. Fig. 16B depicts a fiber designated 1160 having a round cross-section. Fig. 16C depicts a fiber designated 1170 having a square cross-section. Fig. 16D depicts a fiber designated 1180 having a triangular cross-section. While a number of specific shapes for fibers used in the present invention have been disclosed herein, these are merely exemplary of preferred embodiments, and no limitation as to the shapes of fibers used in conjunction with the present invention is contemplated herein. For example, other shapes may be proven to be optimal for certain applications, such as a rectangular (waveguide like) shape, egg-shape (asymmetric oval), “bow tie”, octagon, hexagon, pentagon, parallel-piped, etc. Furthermore, any given fiber need not be restricted to one cross-sectional configuration and/or wall thickness; it is envisaged that various applications of the present invention may utilize fibers having cross-sectional shapes and/or wall thickness that varies as a function of their length.

It will also be recognized that the hollow cores of the fibers used in the illustrated embodiments need not have constant geometries relative to size or shape. The interior walls of the fibers can include various features such as e.g., undulations and modulations of the geometry of the fiber, also optionally in conjunction with changes in the spatial distribution and/or density (or composition of the fuel). Such variations can be used for any number of purposes, including e.g., to induce desired X-ray, UV or other emissions (such as via acceleration of the charged particles), or longitudinal and/or radial “clumping” of the plasma to produce pulses or pulse trains of plasma or its constituent components, or alter

the laser pulse velocity in a given direction. For example, charged particle clumping can be created due to the variation in field density within the fiber core as a function of longitudinal position, whereas neutrons will not be substantially affected or clumped due to a lack of charge.

5 In one simple embodiment, the fiber is tapered at a substantially constant rate as previously described in effect to compress and accelerate the plasma as propagation down the fiber occurs. In a second variant, the rate of taper per linear distance is varied, such that the rate of compression and acceleration is controlled. In a third variant, the thickness of the core channel is varied according to a functional relationship (e.g., a sinusoid or saw-
10 tooth function). In another variant, the channel diameter can conform to a substantially discrete or binary arrangement, wherein step-changes in diameter are provided, thereby creating some degree of backward reflection (in effect inducing a turbulence within the propagating wave). Heterogeneous (i.e., mixed) tapers may also be used within the core (or even within an individual fiber) if desired in order to achieve particular objectives.

15 Similarly, no taper at all (or even an expanding chamber or inverse taper) can be used. This latter seemingly counter-intuitive result stems primarily from the presence of the aforementioned mode-coupling between fibers; e.g., where one or more fueled fibers are surrounded by other fibers, the latter coupling at least a portion of their photon and EM energy into the fueled fibers in order to increase the field intensity within the fueled fibers,
20 even where the lumen diameter is progressively expanding as the wavefront propagates down the fiber(s).

It will also be recognized that the application of external electric or magnetic fields to the fiber can be varied as a function of longitudinal, radial, or angular position if desired. For example, a sinusoidal magnetic flux profile can be created within the fiber core using
25 an externally applied field in order to affect the plasma in a desired fashion, such as e.g., "pinching" the plasma or the pondermotive field.

The externally applied magnetic field may also be used to enhance acceleration of the charged particles formed within the plasma in one direction or another. For example, by creating a transverse magnetic field at the end of the fiber (i.e., at its effluent), charged ions
30 (+ or -) passing through the field feel an orthogonal force which drives the particles in one direction or the other (depending on their charge and the applied field vector). The ejected plasma will be broken into three distinct components: (i) positively charged particles deflected toward one direction; (ii) negatively charged particles in a substantially opposite

direction, and (iii) charge-neutral particles (neutrons, photons, etc.) along the line of initial ejection. By rotating the magnetic field vector rapidly around the longitudinal axis of the fiber (or alternatively rotating the fiber), a frustoconic section of charged particles is created, with a neutral particle jet or stream along its center axis, with the radius of the frustoconic section being related to the strength of the field and its placement relative to the effluent of the fiber.

Such separation of charged and neutral particles may be useful where the two classes of effluent are to be used for different purposes, or where only a substantially charged or un-charged plasma stream is desired. Alternatively, moving the fiber linearly relative to a transverse B-field (or vice versa) will tend to accelerate the ions along their original line of travel (along longitudinal axis of the fiber).

Furthermore, it will be recognized that the fiber core or lumen region need not necessarily be hollow, but could feasibly be formed of a material which allows energy propagation in the longitudinal dimension of the fiber, and the establishment of the desired containment field(s). In a simple case, the core might comprise a gaseous substance having deuterium, tritium, or other fuels atomized and suspended therein. In another variant, one or more segments of solid material (such as an optically transparent polymer) may be disposed within the lumen region. Alternatively, it may be desired to evacuate the core of the fiber from any ambient air or other materials to the maximum degree practicable.

Referring now to Fig. 17, another alternative embodiment of the present invention is shown and generally designated 1200. The fusion core 1200 of this embodiment includes a fiber 1202 formed with a hollow core (not shown in this Figure) and containing a fusion fuel (also not shown). A substantial portion of fiber 1202 is positioned within a cooling chamber 1204 and bathed in a cooling fluid. This cooling fluid, such as water, flows in a first direction 1206 through a pump 1208 and through a cooler 1210 and in direction 1214 for re-introduction into the chamber 1204. It will be appreciated that a counter-flow arrangement may be used as well. In this embodiment, laser radiation 1218 enters fiber 1202, reacts with the fusion fuel therein, and exits as a plasma beam 1220. The cooling fluid circulates in the shown direction 1222, and is recirculated through pump 1208 and cooler 1210 to chill the fiber 1202 by extracting thermal energy therefrom, whether by direct contact with the fiber (conduction), via an interposed medium such as air (convection), and/or simply by absorbing radiated photons and particles (radiation).

In some circumstances, cooling of the fiber 1202 may be necessary to maintain the fiber at a safe temperature and to avoid damage to the fusion core of the present invention. However, such cooling also transfers thermal energy to the cooling medium, which can be used for other productive purposes such as to generate steam, provide heated water. In one
5 variant, the water or other cooling medium is used in conjunction with a recirculating core of the type shown in Figs. 12-13 herein. By continuously (or intermittently) injecting fuel into the fiber core, and pumping with laser energy, a virtually limitless source of heat energy can be exploited. In contrast the embodiment of Fig. 17, this recirculating geometry need not even have an effluent port, since the effluent is not the primary energy source of
10 interest. Rather, the thermal/radiation heating of the fiber (and hence the cooling/heat transfer medium) is paramount.

Similarly, neutron, gamma, and thermal energy can be captured within other fluid volumes disposed proximate to the fiber core. For example, in the case of the helical fiber core geometry described with respect to Figs. 13A-13C, a central chamber disposed within
15 the interior region of the helix can be filled with water or another substance efficient at absorbing the particle/EMR effluent from the fibers, thereby heating the substance or otherwise making use of the radiated energy. In a simple example, a tube or pipe of water can be disposed in the helix interior region, and water recirculated there through, the water being heated on each pass by incident neutron, gamma ray, and infrared radiation.

It will also be appreciated that a refrigerant (R11, R12, R114, etc.) can be used in
20 place of the water loop of Fig. 17 if desired. For example, cool air can be blown or otherwise interfaced with the fiber or core exterior in order to extract heat therefrom. This approach may be preferable to water where high thermal stresses may result in cracking of the fiber or core. It is envisaged, however, that even cryogenic systems could be employed
25 consistent with the present invention, such as for example via a heat exchanger or other indirect conduction/convection mechanism.

In another exemplary embodiment of the invention, a magneto-hydrodynamic (MHD) generator is used in conjunction with the fusion apparatus previously described. An MHD generator of electricity has been likened to a magnet placed onto the exhaust of a
30 turbojet engine. Hot plasma with fully ionized atoms is created within the engine. When the plasma passes through a transverse magnetic field, positive and negative charges are deflected in opposite directions. Collecting plates for the charges provide a DC voltage. The faster the charges can be delivered to the plates, the greater the energy and power capacity

of the generator. With fusion plasmas, the charges are delivered at relativistic speeds approaching c , the speed of light, thereby advantageously delivering very significant energy per unit time.

MHD offers the possibility of very high plasma fuel utilization because of the super high temperatures at which it operates. For the fusion generator, this temperature is in the millions of degrees and correlates with a comparatively high Carnot efficiency. The process is illustrated in the Fig. 18. Unlike early experiments with MHD, the fusion plasma is a highly conductive "fluid" with a large density of free electrons and positively charged ions, and therefore is well adapted to the present application.

In the prior art, MHD generators have been utilized as energy conversion devices powered by the burning of fossil fuels like gas, oil and alcohol. Maximum working fluid temperatures were in the vicinity of 3000 degrees K. Power generation of 50 to 100 MWatts were readily produced. Due to engineering limitations, maximum Carnot efficiency was never much more than 45%. Calculations show that fossil-fueled MHD generators cannot operate at efficiencies greater than approximately 60%.

Unlike turbine generators, MHD power generators advantageously do not require the use of moving solid materials (e.g., blades) in the plasma stream. This means they can operate at much higher temperatures, on the order of millions of degrees K. This kind of robustness and efficiency leads to improved conservation of natural resources, less rejected energy/heat pollution, less maintenance, and significantly lower fuel cost.

The exemplary MHD generator shown in Fig. 18 herein is referred to as a "continuous electrode" Faraday generator. It will be recognized, however, that other MHD designs with alternate geometries may be used consistent with the invention. For such a device, calculations show that the electrical power delivered is proportional to the square of the plasma speed times the square of the magnetic field. The plasma speed in the fusion generator of the present invention approaches the speed of light (i.e., approaching 3×10^8 m/sec). Compared to the roughly 1,000 m/sec speed typical of fossil fuel plasmas; the fusion MHD generator of the present invention can deliver nearly 10^{11} times more power. This is enormous, but further increases are possible. Specifically, conventional superconducting magnets used in MHD generators can create fields of 20,000 Gauss (or 2 Tesla). The magnetic fields associated with Wakefield plasma acceleration from femto-second lasers have been measured at greater than 100 million Gauss. The ratio of magnetic fields is therefore on the order of 5×10^3 . This means that if the fusion plasma fields are

utilized in the MHD generator, power output can be more than 10^{18} times greater than for fossil fuel MHD generators.

Additionally, it will be recognized that the basic principle associated with the MHD may be used to effectively “steer” the plasma ion beam at the effluent (port) of the core.

5 Specifically, with proper application of magnetic field(s), the trajectory of the positive and negative ions present in the plasma can be altered. Such steering may also be used to indirectly affect the trajectory or other properties of other constituents within the plasma effluent, such as where the kinetic interaction of the “steered” charged particles alters the trajectory of neutral particles (e.g., neutrons) disposed within the effluent. Furthermore, so-called “drag” can be used to affect one type of charged particle using another; e.g., where
10 the applied magnetic or electric field is used to steer electrons, whose intrinsic electric field interacts with that of nearby protons in the plasma, the inter-particle field interactions causing an effect on the proton trajectory.

It will also be appreciated that the effluent plasma, particles and energy can be used
15 to power a conventional device such as for example a steam cycle plant or engine. In one embodiment, the effluent radiation is used to heat a working fluid (such as water) to a boiling temperature at the prescribed system pressure, such heat which can then be extracted across the blades of a high or low pressure steam turbine or other such mechanism well known to those of ordinary skill.

20 While the foregoing variants have been described primarily in terms of a conventional (e.g., femto-second) laser, it will be appreciated that the present invention can be practiced using other pumping sources, such as for example an X-ray or UV laser of the type well known in the physics arts. In one exemplary embodiment, the X-rays generated by the laser are coupled into the fiber core(s) of the type previously described herein, to
25 interact with fuel resident therein. However, so-called “charged” Hafnium (such as that recovered from particle accelerator waste or hafnium control rods obtained from nuclear fission reactors) is used as a fuel. As is well known, exposing charged Hafnium to “soft” X-rays (e.g., 90 keV) can induce a gamma ray cascade effect. As can be appreciated, there are many different uses for such a gamma source, including without limitation research,
30 materials testing, weapons, photolithography, or sterilization against microorganisms.

It has been known for many years that the nuclei of some elements, such as Hafnium, can exist in a high-energy state (nuclear isomer) that slowly decays to a low-energy state by emitting gamma rays. For example, Hafnium-178m2, which is the excited, isomeric form of

Hafnium-178, has a half-life of 31 years. The possibility that this process could be rapid in nature was discovered when Carl Collins, et al. (University of Texas at Dallas) demonstrated that the decay of the hafnium isomer could be triggered by bombarding it with low-energy or “soft” X-rays (see, e.g., New Scientist print edition, 3 July 1999; C. B. Collins, et al, Phys Rev Lett 82, 695 (1999), and Collins, et al, Phys Rev 84, 2544 (2000), each incorporated herein by reference in its entirety). Ostensibly, the Collins experiment released many times as much energy as was put in, and in theory greater energy releases can be achieved.

To produce such “charged” Hafnium, energy has to be pumped into its nuclei. The nuclei later return to their lowest energy states through the emission of gamma-ray photons. In one exemplary embodiment of the present invention, the charged Hf is produced by bombarding Tantalum with protons, causing it to decay into Hafnium-178m2 as is well known in the nuclear arts. This can be accomplished using a nuclear reactor or a particle accelerator. Advantageously, only small quantities of the charged Hf (e.g., 178m2) fuel are required to fuel the gamma ray generator of the present invention. Alternatively, the charged Hf can be extracted or refined from nuclear fission reactor control rods or other comparable parts, which have been subjected to extensive irradiation to neutrons, gamma rays, charged particles, etc. created as part of the fission process. As yet another alternative, the Hafnium isomer can be created by bombarding ordinary Hafnium with high-energy photons. See also the methodologies of U.S. Patent No. 6,639,222 to Putvinski, et al. issued October 28, 2003 entitled “Device and method for extracting a constituent from a chemical mixture” incorporated herein by reference in its entirety.

It will also be recognized that since Hf-178m2 can be created by bombarding Tantalum with protons, the energetic protons (and photons) generated through operation of the of the fusion apparatus previously described herein can be used to bombard the Tantalum to produce the Hf isomer, in effect forming a “breeder reactor” of sorts. Specifically, by directing the plasma effluent (or portions thereof, such as that separated by the application of an external magnetic field at the effluent of the fiber as previously discussed) into a quantity of Tantalum, the Tantalum can be converted into the Hf isomer. The isomer can then be used to fuel the gamma ray device previously described. This process can be made as separate steps, or alternatively integrated into one device if desired.

For example, a “first stage” Deuterium-fueled fusion device can be used to bombard Tantalum fuel prior to introduction to the gamma ray device fiber lumen, the bombardment

creating some percentage of Hf isomer within the Tantalum. When the partially isomer-laden fuel is irradiated with the X-ray pump, gamma rays are generated.

As yet another alternative, the process can even conceivably be conducted within a single fiber. Specifically, the Tantalum material can be placed or introduced into the fiber lumen and irradiated with one or more femto-second laser pulses, thereby generating a population of high energy protons in the lumen, which will have a finite probability of interacting with the Tantalum atoms present in the lumen. Those which do interact produce the Hf isomer(s), which can then be pumped with second (set of) pulses from the X-ray laser or other source. This second pump generates the fusion event which produces the gamma radiation in significantly increased quantities.

It will be recognized that the fuel for fusion apparatus discussed above can also be "salted" with the Hf or other isomer, and dual pump sources used. Specifically, in one embodiment, a small fraction (i.e., a few percent) of the weight by mass of the deuterated or other fuel comprises the Hf-178m2 isomer, and the femto-second laser pulse train is punctuated by periodic (or even overlapping) pulses from the X-ray laser. Hence, when no X-ray laser pulses are present, the wavelengths of the femto-second laser are insufficient to generate an significant gamma ray production according to the mechanisms described above. However, in the event that an increase in gamma ray output is desired (such as where the lethality of a weapon against biological targets is desired), the X-ray laser can be switched on, and/or the Hf fuel concentration increased (such as via injection by the fiber wall ports) so as to increase the gamma ray profile emitted from the fiber.

Fuel for this embodiment can also include charged nuclear spin isomers such as from materials other than Hafnium including Thorium and Niobium. It is also envisaged that the fuel can be tailored to emit a spectrum of gamma rays have one or more desired energies, thereby allowing tuning of the effluent for specific purposes. For example, it may be known that certain gamma ray energies are more lethal or penetrating than others, and hence the effluent population can be tuned using proper fuel choice, incident X-ray /UV wavelength and intensity, etc.

As with the femto-second lasers described above, all fiber arrangements, features and geometries are available for use with the X-ray sources, including without limitation, linear and recirculating architectures, bundled or stand-alone fibers, tapered or non-tapered fibers, "modulated" fibers, heterogeneous combinations of fibers, mode-coupling, etc.

Also, the apparatus described above can be used as a recycling facility for materials such as spent (charged) Hafnium or similar waste, rather than burying the same in an underground facility such as Yucca Mountain in Nevada. Specifically, the charged Hafnium is substantially consumed in the extreme environment of the fiber lumen under X-ray pumping. The de-excitation of the Hf or other isomer also releases its stored energy as gamma radiation. Furthermore, by employing a recirculating architecture, the Hf or other isomer can be repeatedly "emptied" to ensure that it is completely reduced to a ground state and passivated. The ejected gamma rays, X-rays, neutrons, plasma, etc. can be harmlessly dissipated in, e.g., a tank of water and/or lead block, or directly into the ground at the site where the apparatus is located.

The foregoing self-contained configuration (Fig. 14) can also be advantageously used with the charged Hafnium or similar fuel, such that a repository of pre-made gamma ray "bullets" are available for subsequent use. Unlike the depleted Uranium munitions now ubiquitous, the bullets of the present invention do not produce a significant amount of activated residual, since the Hafnium is substantially eliminated during the fusion process. Hence, the expended bullets can be stored for a brief period of time to allow any residual activity to decay, after which time they can be disposed of as is any non-activated material.

It will be recognized that while certain aspects of the invention are described in terms of a specific sequence of steps of a method, these descriptions are only illustrative of the broader methods of the invention, and may be modified as required by the particular application. Certain steps may be rendered unnecessary or optional under certain circumstances. Additionally, certain steps or functionality may be added to the disclosed embodiments, or the order of performance of two or more steps permuted. All such variations are considered to be encompassed within the invention disclosed and claimed herein.

While the above detailed description has shown, described, and pointed out novel features of the invention as applied to various embodiments, it will be understood that various omissions, substitutions, and changes in the form and details of the device or process illustrated may be made by those skilled in the art without departing from the invention. The foregoing description is of the best mode presently contemplated of carrying out the invention. This description is in no way meant to be limiting, but rather should be taken as illustrative of the general principles of the invention. The scope of the invention should be determined with reference to the claims.

WHAT IS CLAIMED IS:

1. Fusion apparatus comprising at least one electromagnetic energy source adapted to transmit high-intensity pulses of electromagnetic energy to at least one fuel element disposed at least partly within a containment element having a substantially longitudinal cavity formed therein, thereby inducing nuclear fusion and a substantially directional plasma output, the direction of said plasma output being substantially coincident with a longitudinal dimension of said cavity.
2. A fusion device, comprising:
 - a laser light source;
 - an optical fiber formed with a substantially hollow core;
 - a fusion fuel disposed within said substantially hollow core, wherein said laser light source emits laser radiation into said core and said laser radiation reacts with said fusion fuel to initiate a fusion reaction.
3. The fusion device of Claim 2, wherein said laser light source is a pulse laser.
4. The fusion device of Claim 3, wherein said pulse laser is a femto-second laser.
5. The fusion device of Claim 3, wherein said laser light source has a power level of at least 1×10^{18} watts per square centimeter.
6. The fusion device of Claim 2, wherein said light source is a continuous laser.
7. The fusion device of Claim 2, wherein said fiber comprises a holey fiber.
8. The fusion device of Claim 2, wherein said fiber is a single-mode fiber.
9. The fusion device of Claim 2, wherein said fiber is a multi-mode fiber.
10. The fusion device of Claim 2, wherein said fiber is formed with at least one tapered region.
11. The fusion device of Claim 10, wherein said tapered region comprises a tapered ejection end which forms a waveguide having a diameter of less than $1/n$ wavelength of said laser light source, where n is an integer.
12. The fusion device of Claim 2, wherein at least a portion of said fiber is coated with a material adapted to reflect neutrons.
13. The fusion device of Claim 2, wherein at least a portion of said fiber is coated with a material adapted to reflect photons.
14. The fusion device of Claim 2, wherein said fiber comprises quartz.
15. The fusion device of Claim 2, wherein said fiber comprises silica.

16. The fusion device of Claim 2, wherein said fiber comprises glass.

17. The fusion device of Claim 2, wherein said fiber comprises non-glass materials.

5 18. The fusion device of Claim 2, wherein said fiber comprises at least one polymer.

19. The fusion device of Claim 2, wherein said hollow core fiber comprises composite materials.

20. The fusion device of Claim 2, wherein said fiber comprises layered materials.

10 21. The fusion device of Claim 2, wherein said fusion fuel is coated within said hollow core of said fiber.

22. The fusion device of Claim 21, wherein said fuel comprises deuterium.

23. The fusion device of Claim 22, wherein said fuel further comprises tritium.

24. The fusion device of Claim 2, wherein said fuel comprises water.

15 25. The fusion device of Claim 2, wherein said fuel comprises a gas.

26. The fusion device of Claim 2, wherein said fuel comprises a gas and/or a liquid, and said fiber includes a plurality of passages formed therein to transfer said gas and/or liquid into said substantially hollow core.

20 27. The fusion device of Claim 2, wherein said fuel is ionized within said hollow core of said fiber.

28. The fusion device of Claim 21, wherein said fuel comprises palladium.

29. The fusion device of Claim 21, wherein said fuel comprises a metal selected from the group of platinum, palladium, titanium, lithium 6, lithium 7, gold, or uranium.

25 30. A fusion core, comprising:
an optical fiber formed with a hollow core for receiving fusing energy;
a fusion fuel within said hollow core, wherein said energy reacts with said fusion fuel to initiate a fusion reaction.

31. The fusion core of Claim 30, wherein said energy comprises laser radiation emitted from a pulsed laser.

30 32. The fusion core of Claim 30, wherein said fiber comprises a holey fiber, and said core comprises a plurality of said fibers disposed substantially parallel and substantially proximate to one another.

33. A method for creating a fusion reaction, comprising:

providing a fiber formed with at least one lumen region;
introducing a fusion fuel into at least one of said at least one lumen region;
introducing electromagnetic radiation into said lumen region, wherein said radiation strikes said fusion fuel to produce a fusion reaction.

5 34. The method of Claim 33, wherein said act of providing a fiber comprises providing a single-mode holey fiber.

 35. The method of Claim 33, wherein said act of providing a fiber comprises providing a multi-mode holey fiber.

10 36. The method of Claim 33, wherein said act of introducing radiation comprises introducing radiation having a power density in excess of 10^{15} watts/cm².

 37. The method of Claim 33, wherein said radiation is provided by a pulse laser.

 38. The method of Claim 37, wherein said pulsed laser is a femto-second laser.

15 39. A method of inducing a fusion reaction wherein fuel is introduced into a fiber lumen through a substantially porous wall of said fiber, said fuel being fused by electromagnetic energy introduced into said lumen.

 40. A method of inducing a fusion reaction wherein fuel is embedded into a wall of a fiber having a lumen, said fuel being released into said lumen by at least elevating the temperature of said wall, said fuel being fused by electromagnetic energy introduced into said lumen.

20 41. A fusion core, comprising:
 at least one fiber having a central region and containing a fusion fuel, said fiber being adapted to receive electromagnetic radiation from a radiation source to create a desired electromagnetic radiation intensity within said central region, said desired intensity being sufficient to fuse at least a portion of said fuel.

25 42. Fusion based particle collider apparatus, comprising at least first and second fusion apparatus disposed relative to one another so as to have at least a portion of their effluent particle beams collide.

 43. The apparatus of Claim 42, wherein said first and second fusion apparatus each comprise at least one holey fiber.

30 44. The apparatus of Claim 42, wherein said first and second fusion apparatus each comprise at least one laser capable of generating femto-second or shorter pulses.

 45. The apparatus of Claim 42, wherein said first and second fusion apparatus each comprise at least one recirculating fiber architecture.

46. Fusion-based gamma ray producing apparatus, comprising:
at least one fiber having an isomeric fuel disposed at least partly within the lumen of
said fiber; and

an electromagnetic source adapted to couple electromagnetic radiation into said fiber
5 to fuse said fuel, said fusion producing said gamma rays.

47. The apparatus of Claim 46, wherein said isomeric fuel comprises Hf178m2 ,
and said electromagnetic radiation comprises soft X-rays.

48. Fusion-based breeder reactor apparatus, comprising:

a proton source comprising at least one energy source, a fiber and a fusion fuel; and
10 a first material capable of becoming charged under proton irradiation.

49. The apparatus of Claim 48, wherein said energy source comprises a femto-
second laser, and said first material comprises Hafnium-178.

50. The apparatus of Claim 49, wherein said fiber comprises a holey fiber, and
said fusion fuel comprises a low-Z species.

15 51. Fusion core apparatus having a plurality of hollow channels and a plurality of
interstitial regions, wherein said interstitial regions are used to introduce fuel into at least a
portion of said hollow channels through the walls of said at least portion of channels.

52. The apparatus of Claim 51, wherein said walls are adapted to pass said fuel
through a plurality of micro-channels formed therein.

20 53. The apparatus of Claim 51, wherein at least a portion of said interstitial
regions further contain a neutron reflector material.

54. Fusion containment apparatus a fiber having a lumen region, said lumen
region being configured to contain or receive fusion fuel, and also receive electromagnetic
energy, said energy cooperating with said fiber to generate a containment field and to fuse said
25 fusion fuel, said containment field being sufficient to contain at least a portion of the
byproducts of said fusing in at least one dimension.

55. Electricity producing apparatus powered substantially by nuclear fusion,
comprising:

a laser source;

30 a substantially longitudinal fiber having a lumen formed therein;
fusion fuel disposed at least transiently within said lumen; and
electricity generating apparatus;

wherein said laser source, fiber and fuel cooperate to generate a plurality of subatomic species, said species being used to power said electricity generating apparatus.

56. The apparatus of Claim 55, wherein said generating apparatus comprises an MHD device.

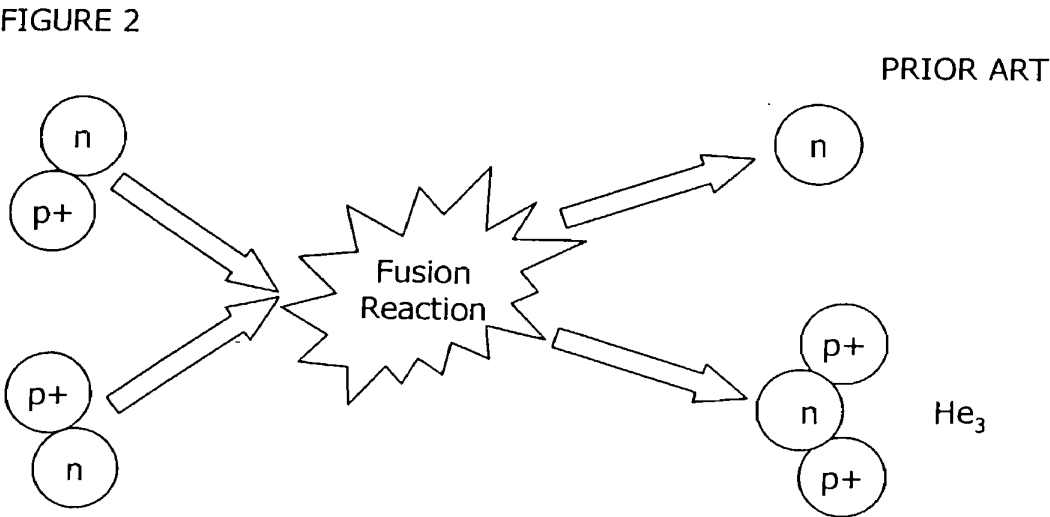
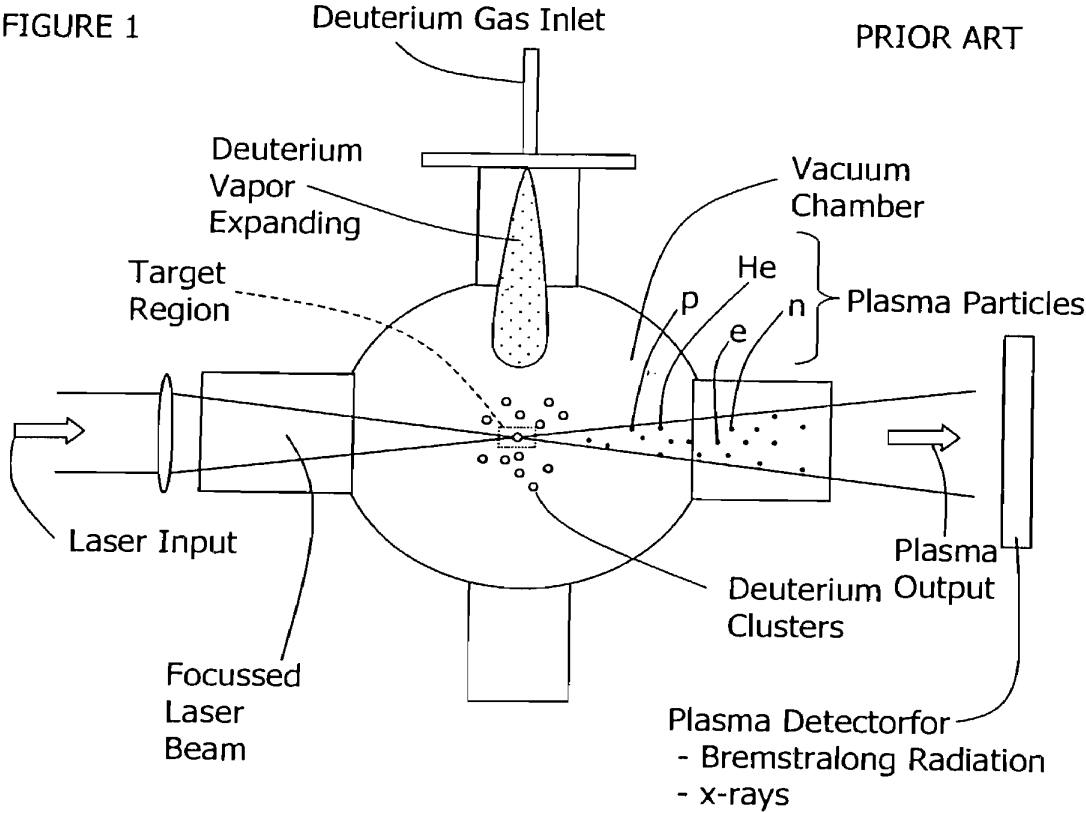
5 57. The apparatus of Claim 55, wherein said generating apparatus comprises an steam powered device powered at least in part from steam generated by capturing said subatomic species in water.

58. Fusion apparatus comprising at least one femto-second laser adapted to transmit high-intensity pulses of electromagnetic energy to at least one fusion fuel disposed at
10 least partly within a holey fiber containment element having a substantially longitudinal and tapered lumen formed therein, said electromagnetic energy inducing nuclear fusion and a substantially directional plasma output, the direction of said plasma output being substantially coincident with a longitudinal dimension of said cavity.

59. A method of producing nuclear fusion, comprising:
15 providing a plurality of substantially parallel channels within a medium;
providing a laser energy source producing energy below the damage threshold of said medium;
disposing a fusion fuel within at least one of said channels;
introducing laser energy from said source into a first plurality of said channels
20 including said at least one fueled channel;
mode-coupling energy from said first plurality of channels into said at least one fueled channel; and
generating a fusion event within said at least one fueled channel using both said introduced energy and said mode-coupled energy.

25 60. Portable fusion powered plasma beam weaponry, comprising a femto-second laser and a power source for said laser, and at least one hollow channel having a fusion fuel disposed therein, said laser, channel and fuel cooperating to generate said plasma beam as a result of nuclear fusion.

61. A method of inducing a fusion reaction wherein fusible fuel is introduced
30 into a fiber lumen through at least one port formed in the wall of said fiber, said fuel being fused by electromagnetic energy introduced into said lumen substantially concurrent with said fuel.



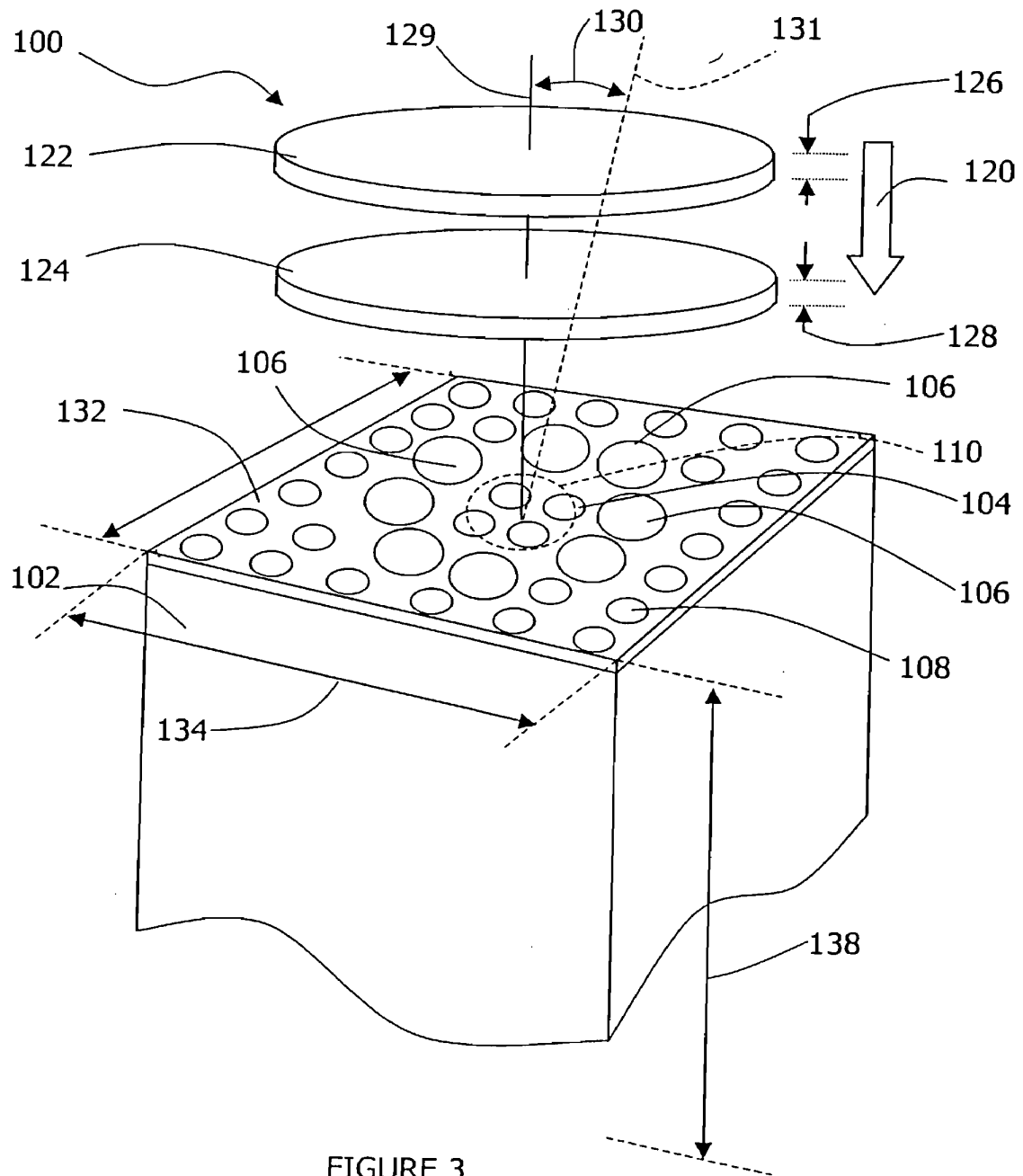


FIGURE 3

FIG. 3A

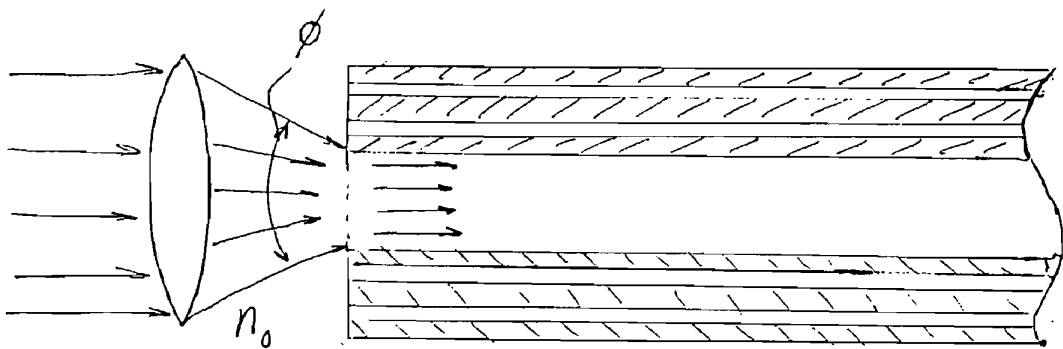
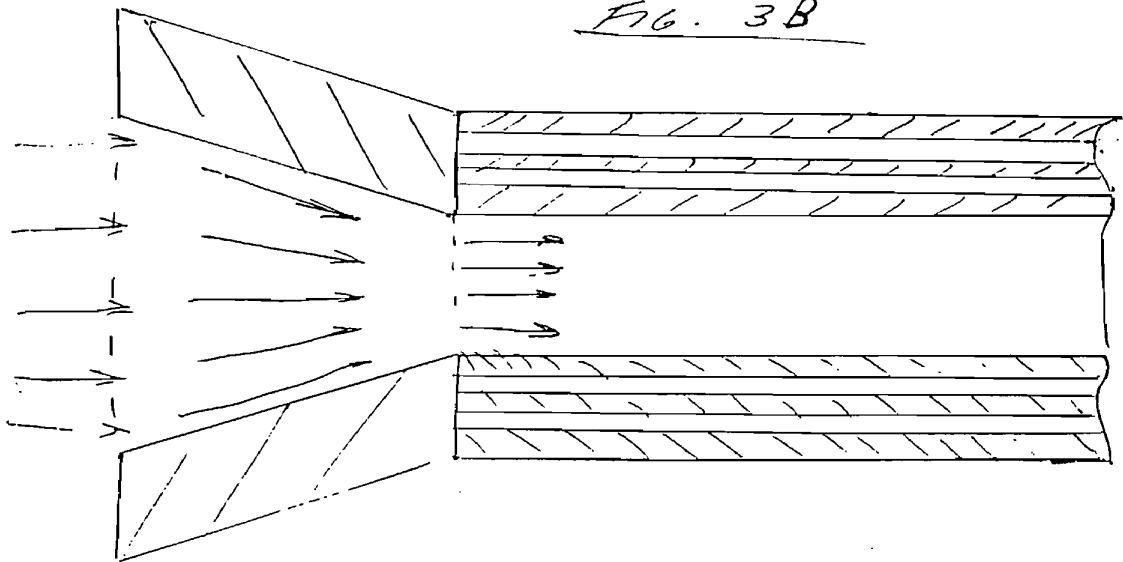


FIG. 3B



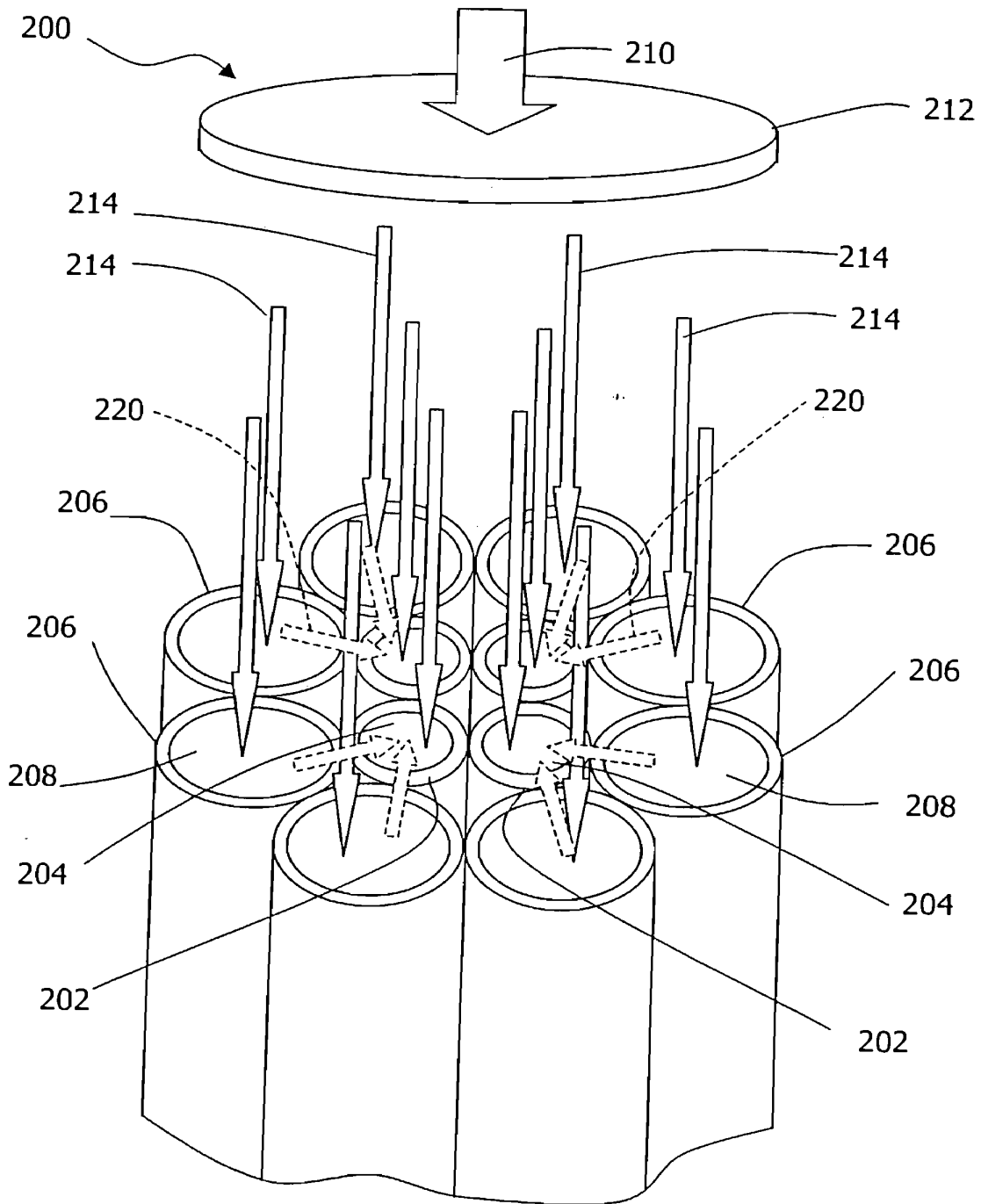


FIGURE 4

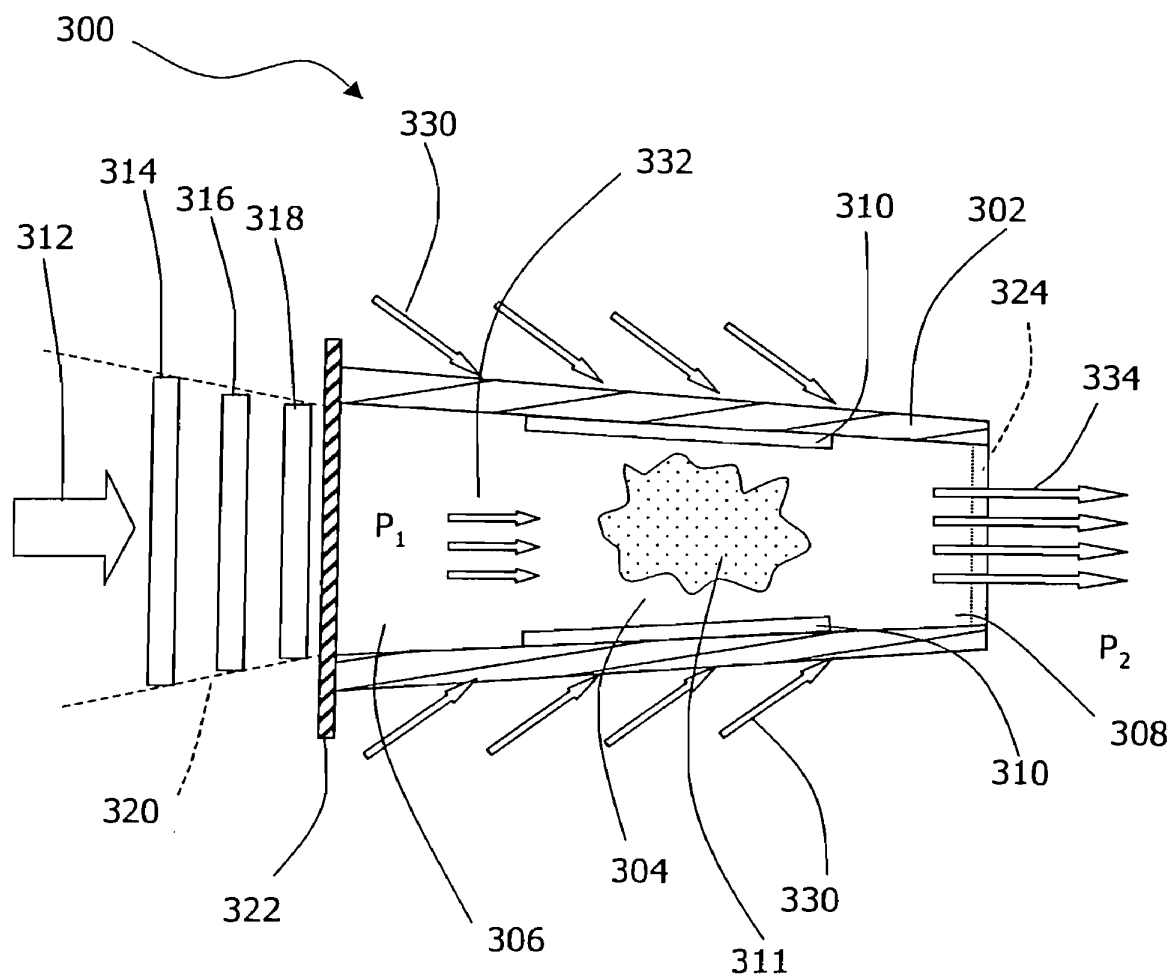


FIGURE 5

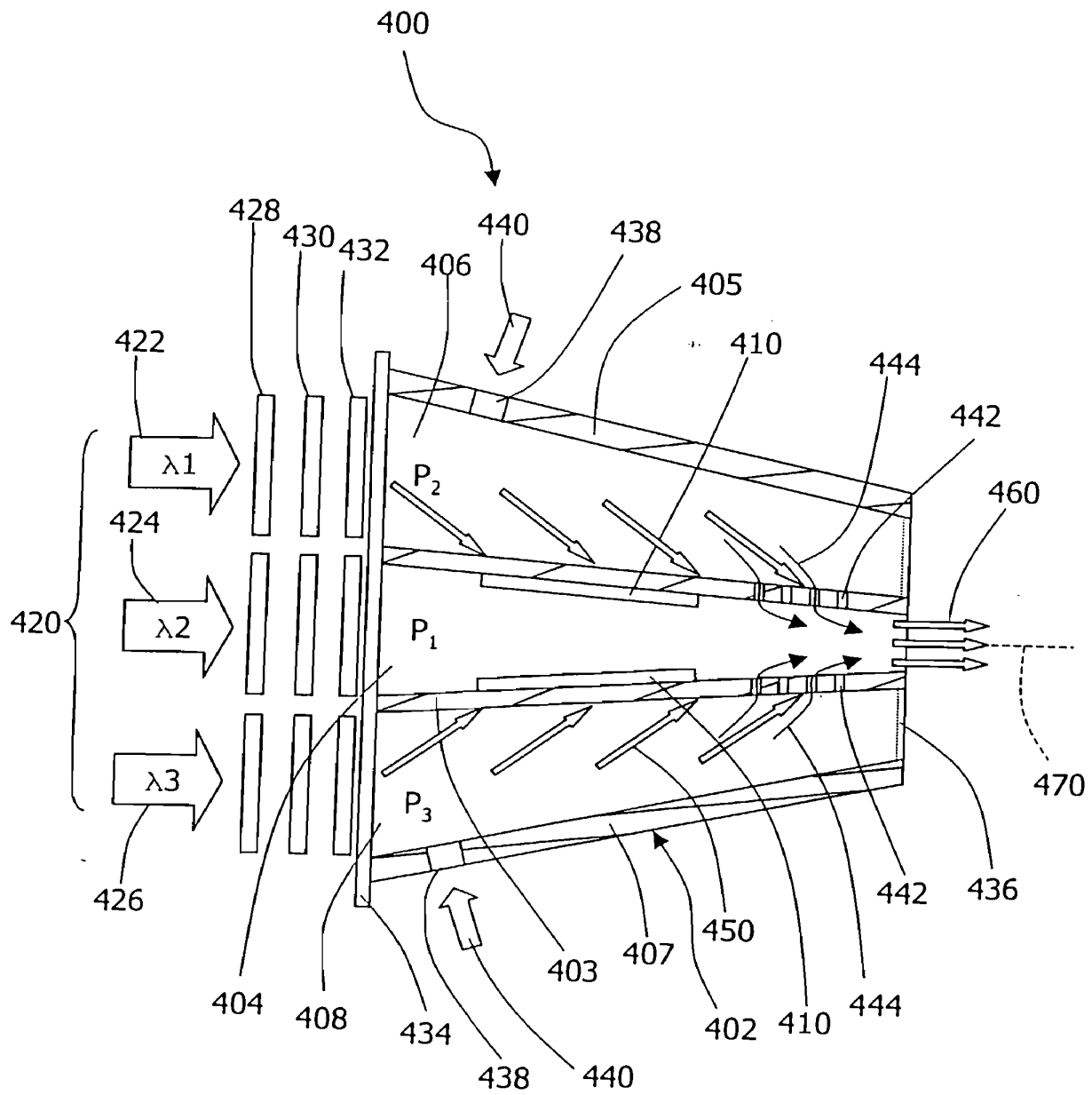


FIGURE 6

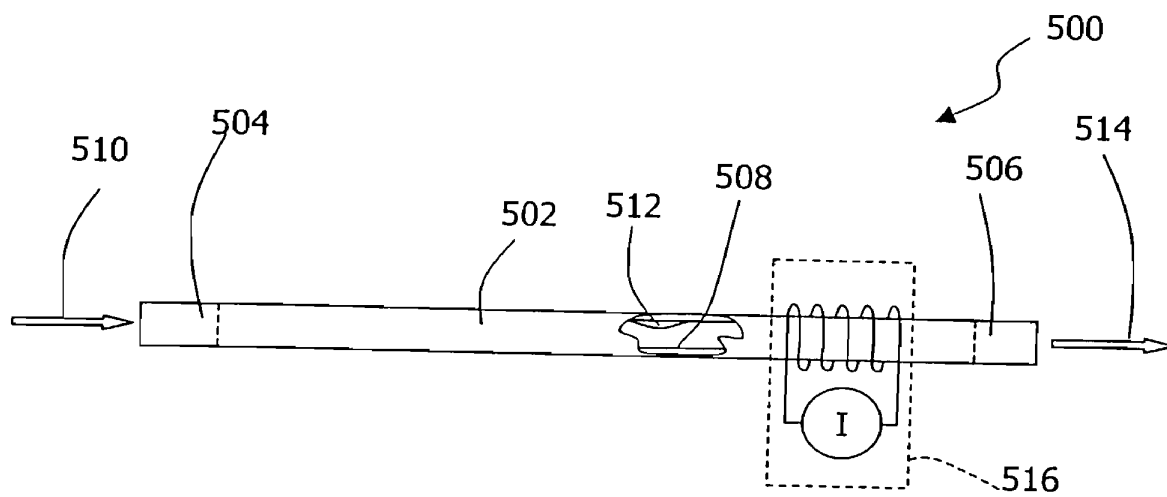


FIGURE 7

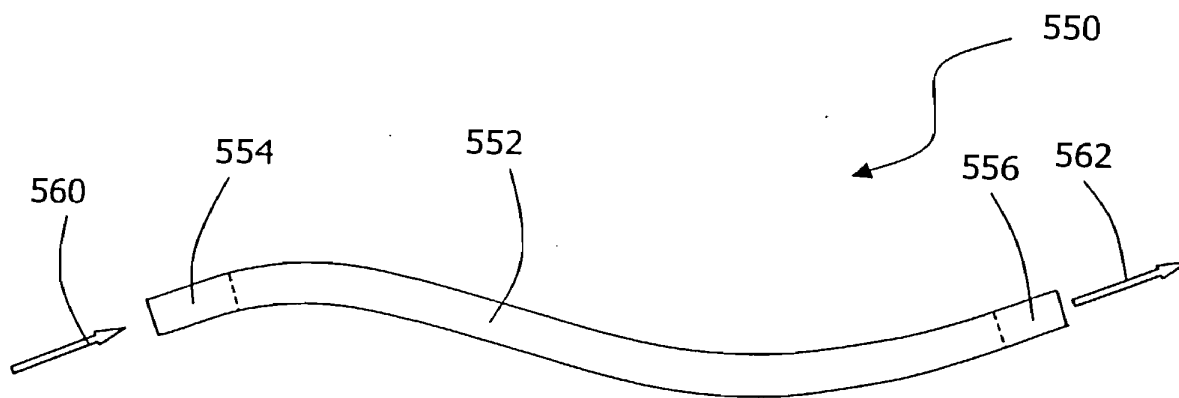
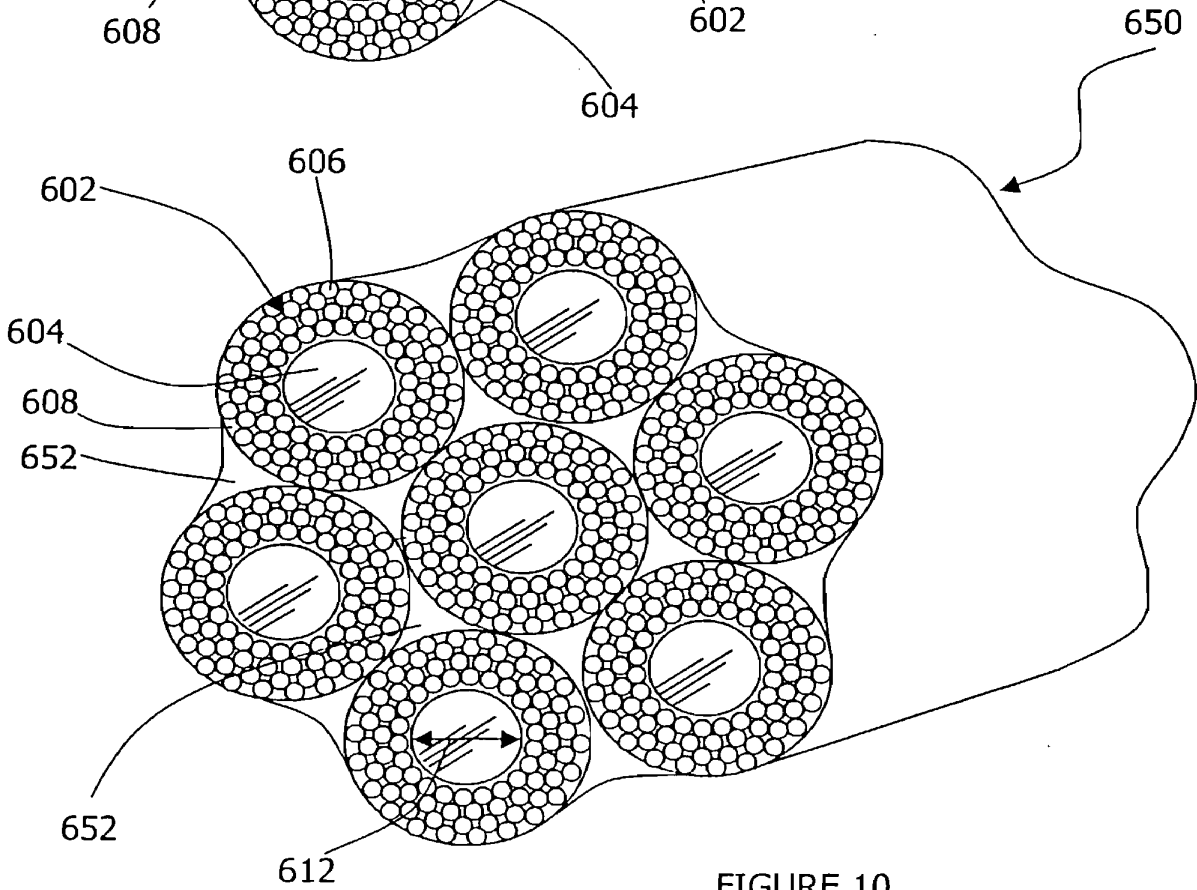
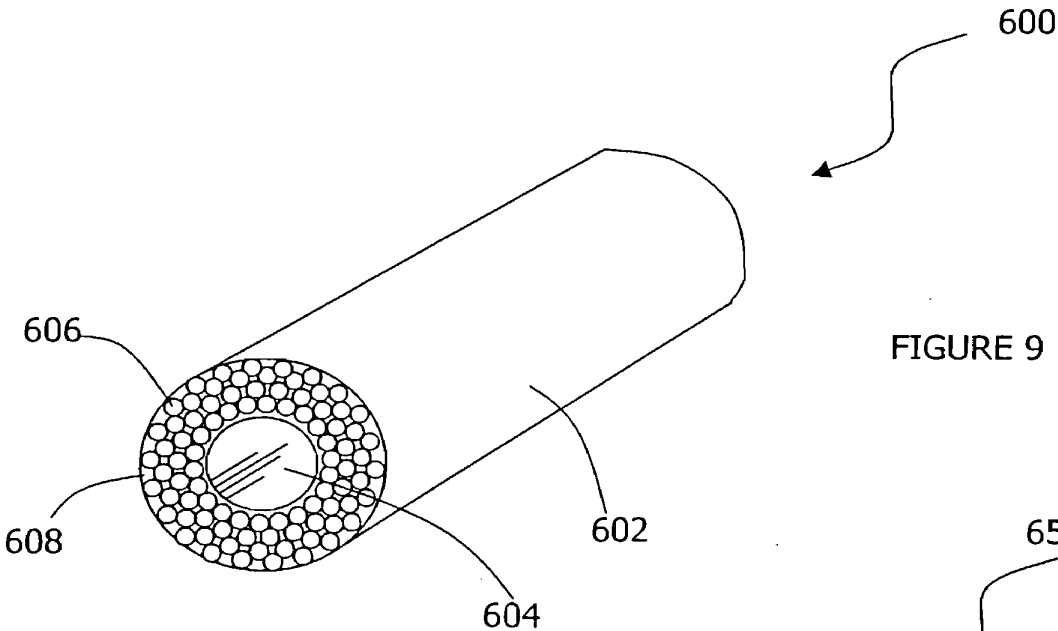
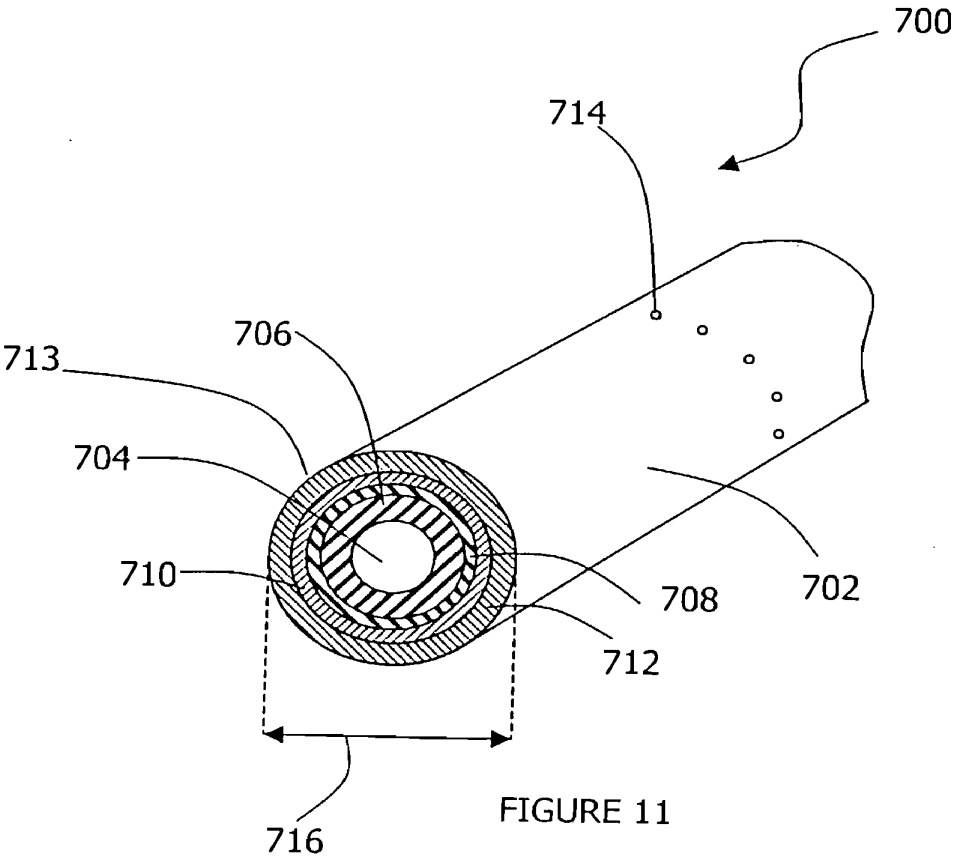


FIGURE 8





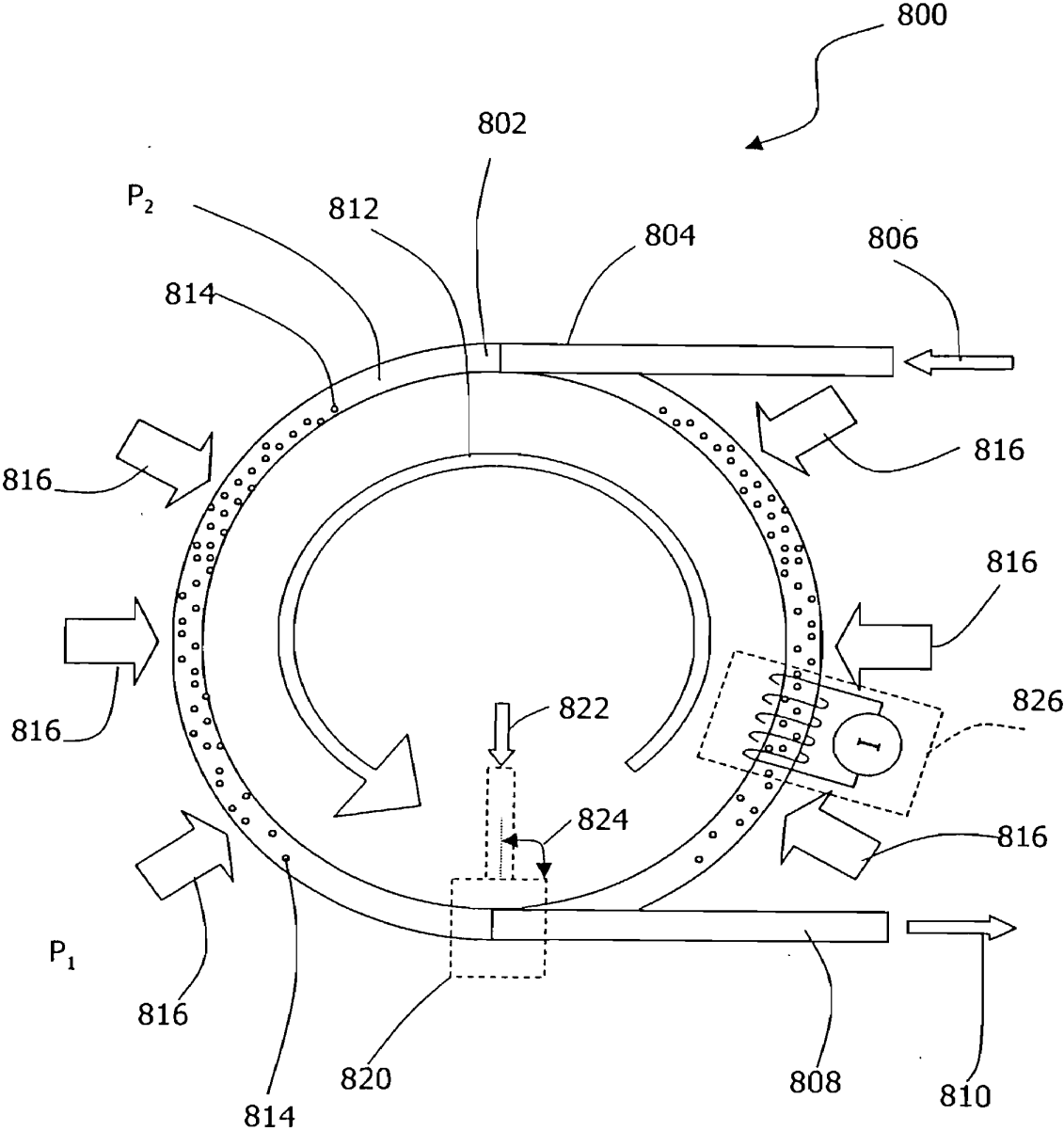


FIGURE 12

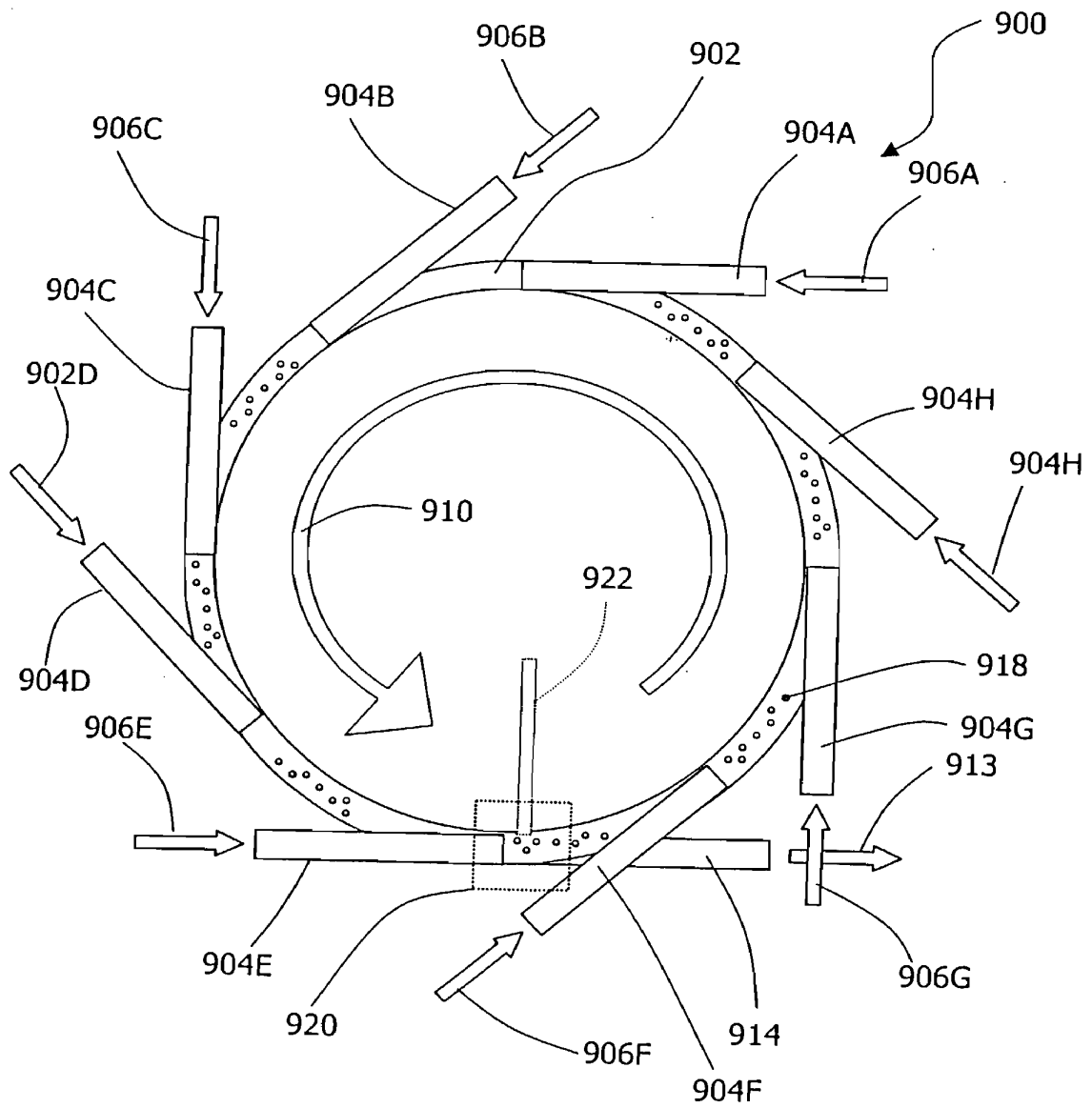


FIGURE 13

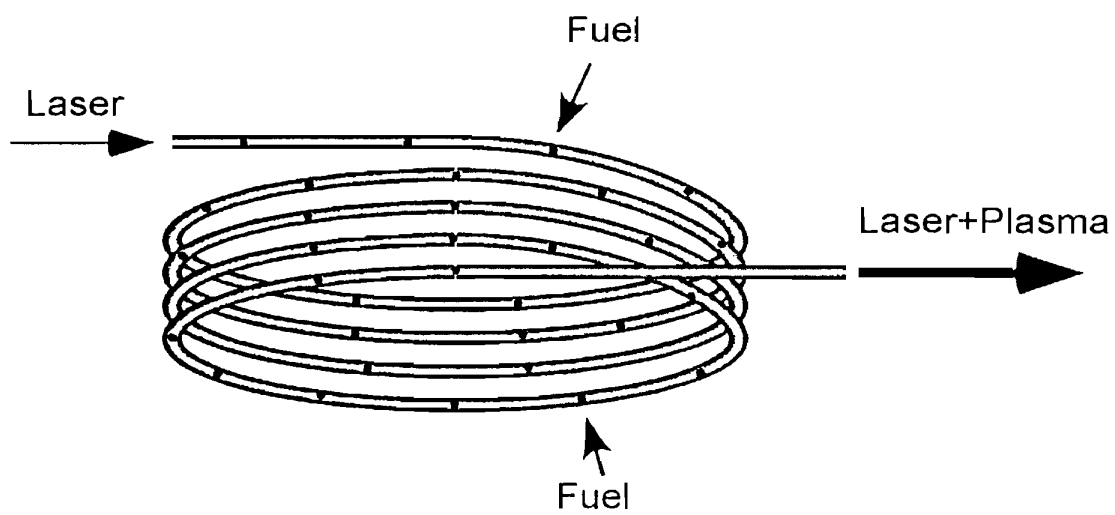


Fig. 13A

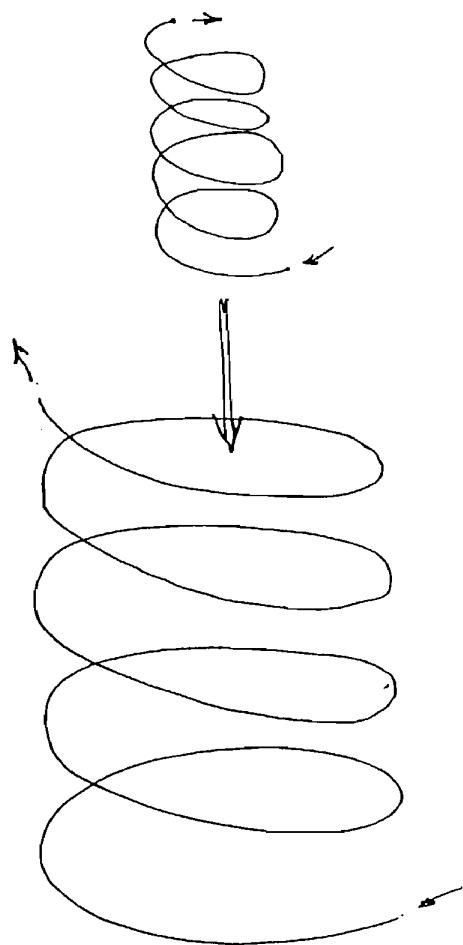
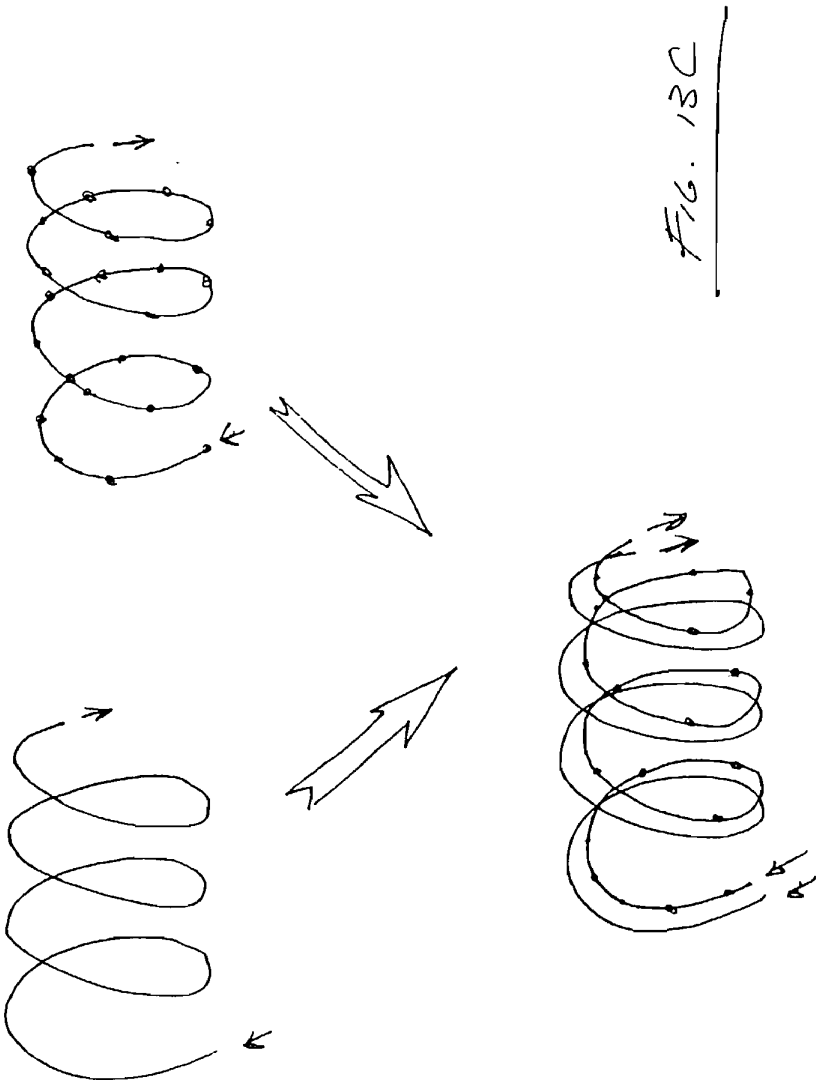


Fig. 13B



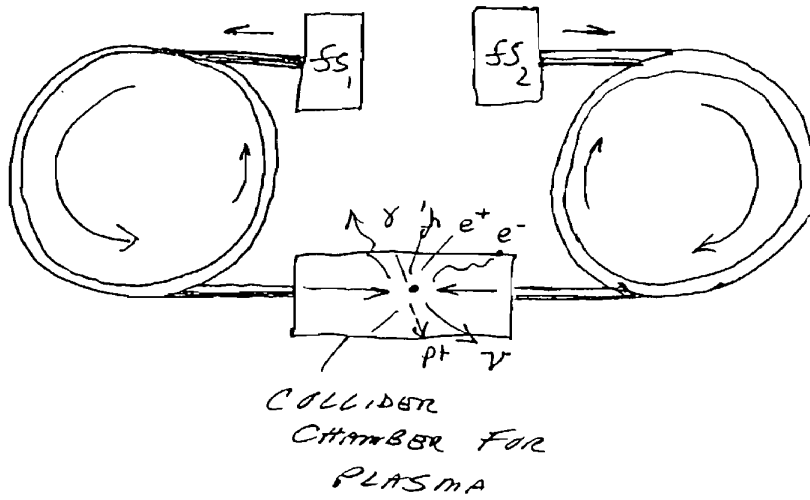


FIG. 13D

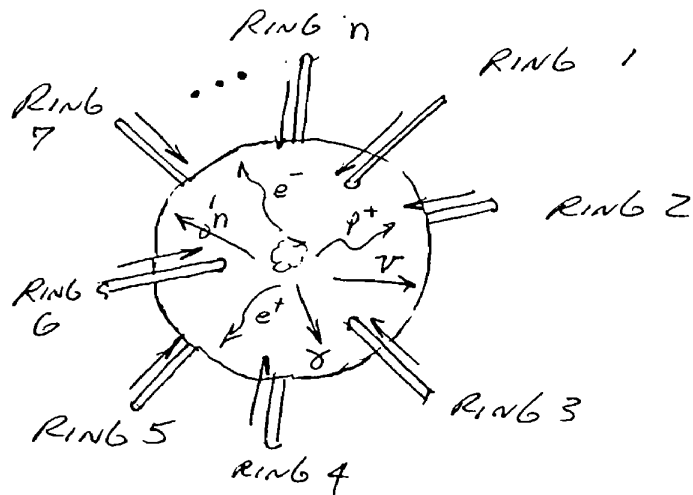


FIG. 13E

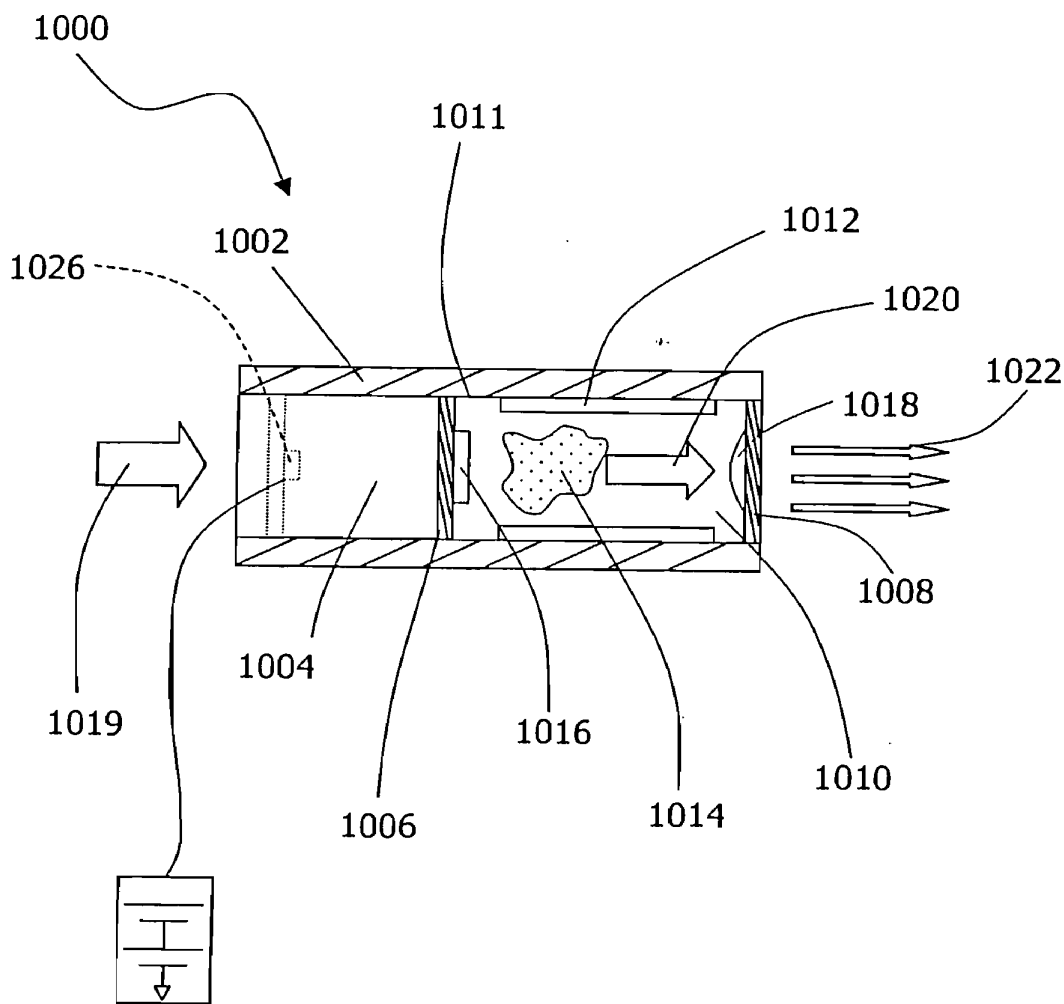
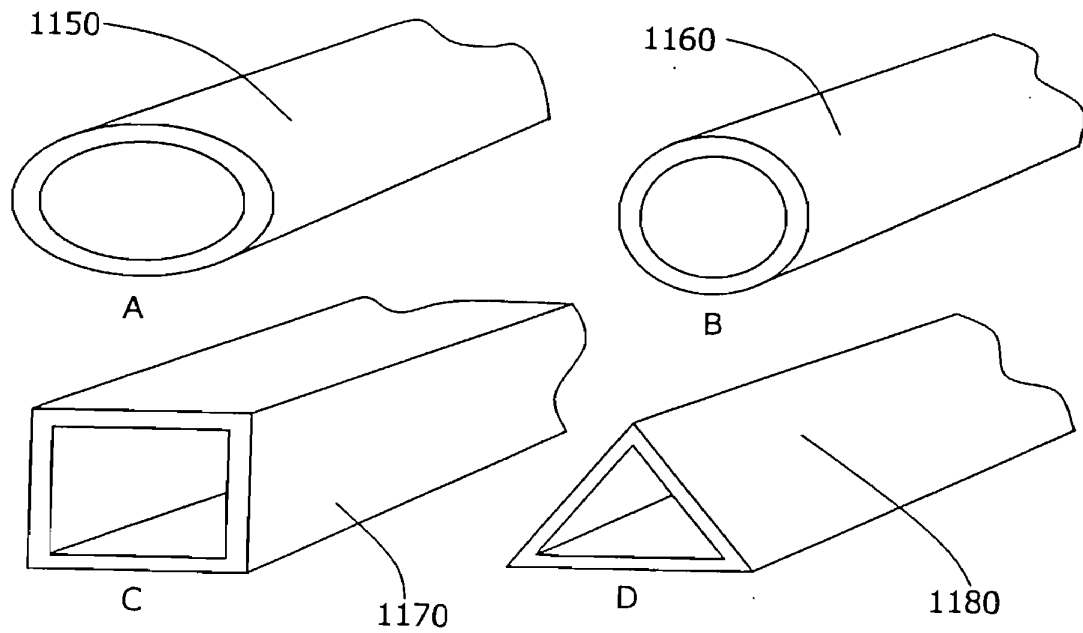
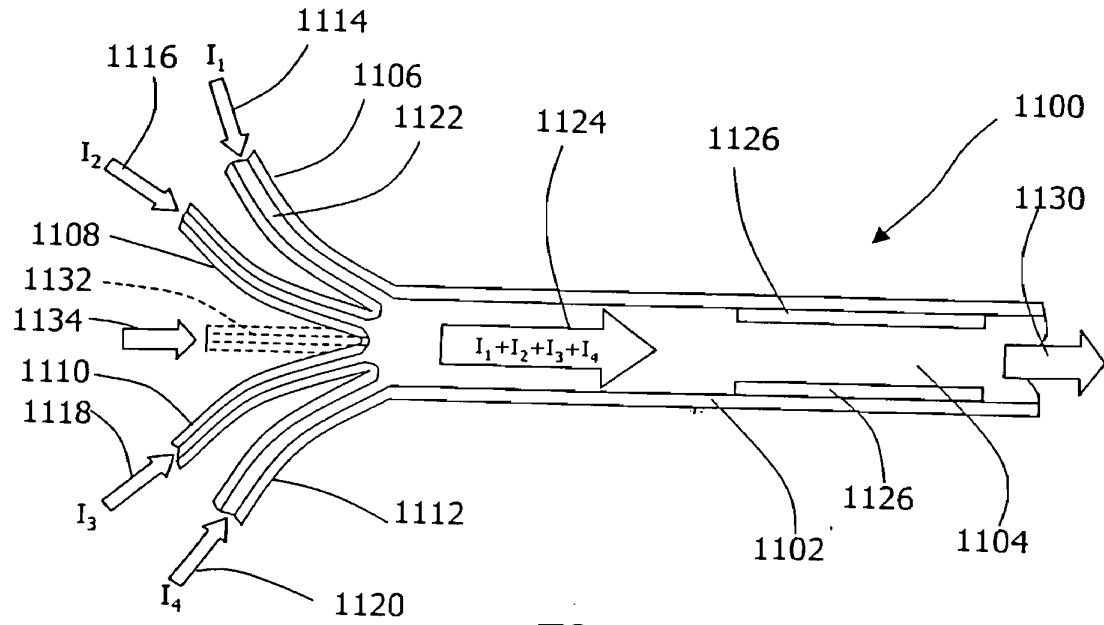


FIGURE 14



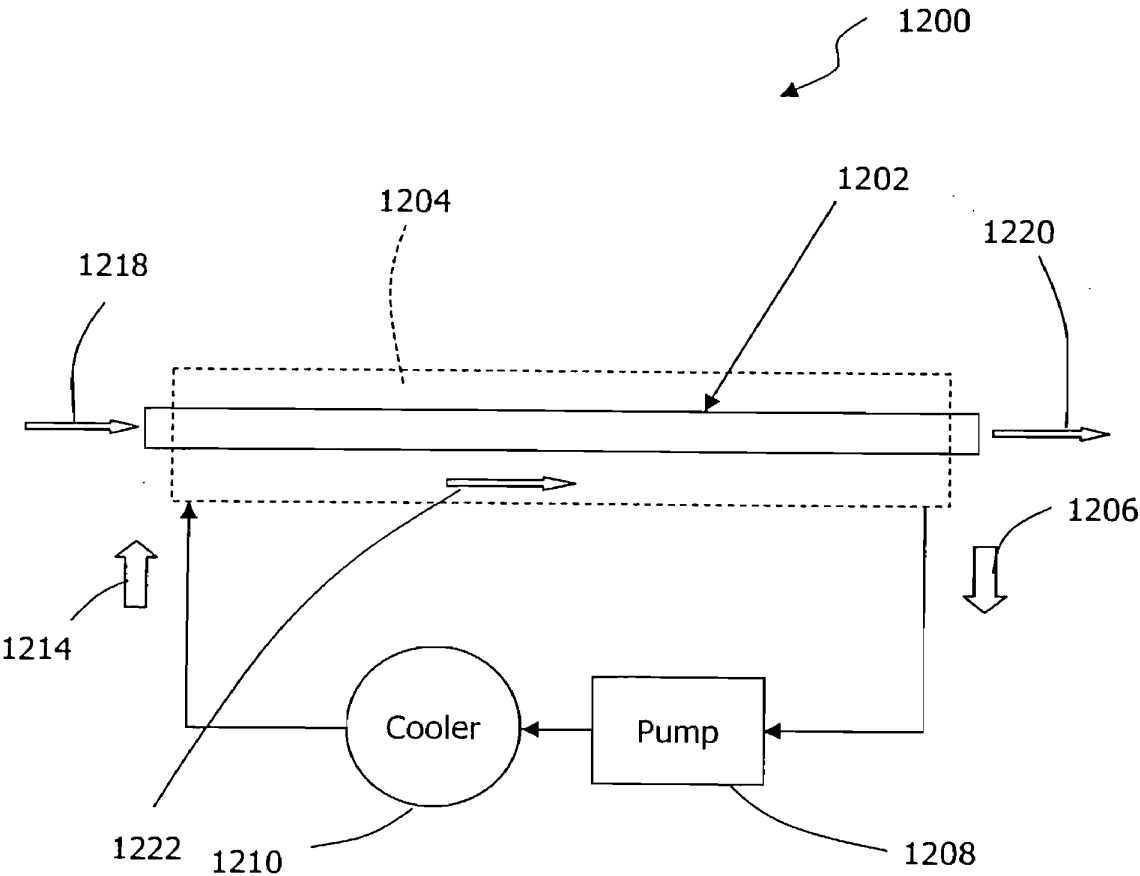


FIGURE 17

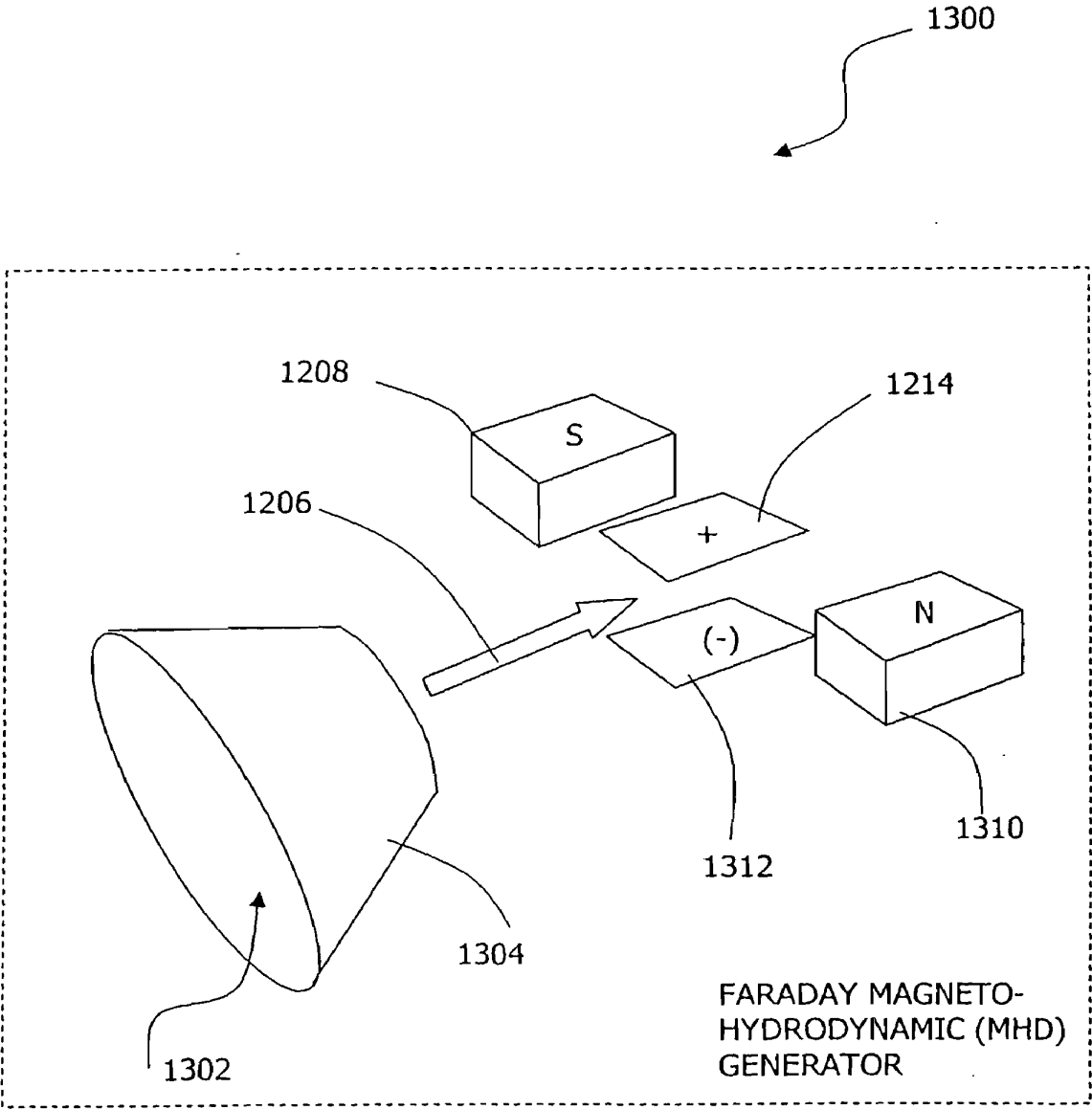


FIGURE 18

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- of inventorship (Rule 4.17(iv)) for US only

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(54) Title: CONTROLLED ALPHA MULTIPLICATION DEVICE

(57) Abstract: The present invention is directed to a method and apparatus of initiating and sustaining a cold fusion process to generate energy comprising subjecting deuterium atoms contained in a deuterium rich system capable of having a PF of at least 0.5 to alpha radiation derived from an external source to initiate fusion of deuterium atoms and controlling the total energy output of said system and the nuclear fusion of deuterium by varying the number of alpha particles externally supplied to the deuterium rich system while maintaining the system PF at from 0.5 to 1.



WO 2005/065095 A2

Controlled Alpha Multiplication Device

FIELD OF THE INVENTION

The present invention is directed to the production of energy by fusion of deuterium atoms.

BACKGROUND OF THE INVENTION

Solar energy provides approximately 5 million quadrillion British Thermal Units (BTU's) annually (1360 watts per square meter) to the upper atmosphere of the earth. In contrast, in the United States about 94 quadrillion BTU's of energy was produced in 1997 from various fuel sources in order to supply about 353 million BTU per capita. A little over one third of this energy was used to produce electricity, with an average conversion efficiency of about 35% (to give 13,000 kwhr per capita per year); a little over one quarter was used for transportation; and the rest was used to produce heat for other needs.

The use of petroleum, natural gas, coal and biomass fuel as sources of energy have caused concerns ranging from pollution and greenhouse gas production to rising prices and politically unstable sources. Other energy sources have their own problems. Wind and hydropower are limited or unreliable sources of energy; conversion of solar power to electricity is expensive; and nuclear power is burdened with safety, security and disposal concerns. A new means of providing energy with greater benefits and fewer problems is needed.

These needs have led researchers to consider nuclear fusion as a source of energy for three reasons. First, the raw materials for nuclear fusion abound on our planet. For example, deuterium is available in water. Second, fusion of atomic particles produces more energy for a given amount of material than

virtually any other known source of energy. Finally, nuclear fusion holds strong promise as an environmentally safe process.

The generation of energy through high temperature fusion of hydrogen has been known. As is known there are three isotopes of hydrogen: protium having
5 one proton in its nucleus is the isotope in largest abundance; deuterium having one proton and one neutron occurs naturally as part of hydrogen mass at a concentration of about 0.015% (1 in 6000 atoms); and tritium, with one proton and two neutrons, is radioactive and not found in nature. Protium is not considered a candidate for fusion reaction on earth, although it is the primary fuel consumed in
10 the sun. Tritium is also an undesirable candidate due to its radioactivity.

Fusion has been actively investigated because of the large amount of energy capable of being produced. For example, the combustion of one pound of hydrogen as fuel yields about 69,000 BTU of heat while the combustion of one pound of carbon (or coal) yields only about 14,000 BTU. Fusion of a small amount
15 of deuterium present in that same one pound hydrogen mass will yield over 500 times more energy. The same amount of pure deuterium has the potential of yielding over 3 million times as much energy by fusion as achieved by the combustion of the same weight of hydrogen.

Deuterium has been fused at very high temperatures to produce heavier
20 nuclei with a concurrent release of energy. A high temperature fusion reactor normally utilizes plasma (a high temperature, highly ionized but electrically neutral "gas") to cause the fusion of two deuterium nuclei. The process does not simply produce helium and heat. Instead, it is believed that when two deuterium nuclei are forced together at high temperatures, the resulting
25 agglomerate is so highly energetic that it ejects one of the four particles (two protons and two neutrons) in combination with some (kinetic) energy. Half the time a proton is ejected, leaving a tritium nucleus, and half the time a neutron is ejected, leaving an isotope of helium, ^3He . High temperature fusion reactions have been demonstrated in the laboratory and in weapons, but controlled power

generation has not been achieved with useful output. The main problem is the requirement for equipment that will produce and operate at very high temperatures with complete product confinement and shielding from neutrons.

Some investigators have recently reported that after many days of electrolysis of deuterium oxide (heavy water) using a palladium electrode, some of the conducted experiments developed excess heat which they proposed to indicate nuclear fusion. However, they did not find evidence for neutrons in amounts needed to correlate the heat evolved with the theory developed for high temperature fusion. The absence of neutrons and the difficulty in reproducing their results have caused the majority of nuclear physicists to reject the possibility of "cold" nuclear fusion reactions. On the other hand, other researchers have occasionally reported observing excess heat from deuterium-palladium and related experiments. Many papers have been published on the topic but, to date, the results have been sporadic.

Problems with the attempts to achieve cold nuclear fusion revolve around reproducible initiation of the process and control and propagation of the initiated reaction. To date, conditions under which one can reliably conduct a cold nuclear fusion process have not been determined.

It is the purpose of the present invention to provide a process that reliably achieves cold nuclear fusion and the production of energy therefrom. Specifically, the present invention defines the components that can provide for initiation of the reaction and for the propagation and control of the initiated process. The present invention further provides an apparatus that produces heat by utilizing deuterium fusion reaction under low temperature conditions.

SUMMARY OF THE INVENTION

The method of the present invention comprises subjecting deuterium atoms to alpha radiation derived from an external source to initiate fusion of the

deuterium atoms. The fusion of deuterium causes the formation of helium with the liberation of heat and the internal generation of alpha particles. The alpha particles generated internally by the fusion reaction, either alone or supplemented by additional alpha particles from the external source, propagate the fusion
5 reaction. The propagation can be maintained at a desired level by controlling the amount of alpha particles generated internally and the number of alpha particles provided through supplementation from the external source.

DETAILED DESCRIPTION OF THE INVENTION

10 The following terms used throughout the present specification and the appended claims have the definition provided herein below:

a) "alpha source" is a material capable of emitting alpha particle
15 radiation comprising radioactive material such as radium, americium, plutonium, or any of the elements heavier than bismuth, which are radioactive by alpha decay, or radon in solution of electrolyte or in D₂ gas.

b) "alternative alpha source" shall mean lithium, beryllium or boron or
20 other elements which produce alpha particles when subjected to irradiation with neutrons.

c) "channeling material" shall mean metals such as palladium, platinum, titanium, magnesium, scandium, nickel, yttrium, vanadium, erbium, holmium, lutetium, thulium, tantalum, their alloys, deuterides (as defined below), carbon nanotubes, and other alloys that absorb relatively large quantities of
25 hydrogen. (Alloys that absorb large quantities of hydrogen are suggested as storage media for fuel purposes; these include Ti₅Fe₄Ni, TiFe, Ti₅Cr₉, LaNi₅, CaNi₅, Ba₇Cu₃, K₂Zn, K₃Zn, TiV, TiMnV mixtures, TiMn₂ mixtures, ZrCo mixtures, NiMn mixtures, and ZrTiVNi mixtures. Such materials have a highly ordered atomic lattice structure with long interstitial spaces or channels and are

capable of adsorbing or absorbing or otherwise containing large quantities of deuterium therein. The particular dimensions of the interstitial spaces will depend on the nature of the metal being used to form the channeling material. The length of the channels should be at least an average of 2 microns, with from 2 to 25,000
5 microns or even higher being acceptable and from 50 to 25,000 being preferred. Although materials having higher average lengths are preferred for greater reaction, they are usually more difficult to form and thereby incur an economic restraint on their availability. In most instances, the metal can be readily annealed to provide interstitial spaces averaging from about 50 to 2,000 microns or greater
10 in length. In most cases, materials of high average lengths are preferred for greater reaction. In certain instances, shorter channel length may be desired as a means of limiting the amount of reaction. In addition, channeling material can be a non-metal, such as carbon in the form of nanotubes and deuterides, as described below.

15 d) "surface layer materials" shall mean two-dimensional channel materials such as platinum or nickel or a layer-containing material like graphite (as contrasted with a one-dimensional channel-containing material) which can adsorb or absorb or otherwise contain large quantities of deuterium.

e) "deuterides" shall mean deuterated compounds of metals such as
20 aluminum, barium, calcium, cerium, chromium, gadolinium, hafnium, lanthanum, lithium, magnesium, manganese, nickel, niobium (columbium), potassium, sodium, strontium, titanium, thorium, uranium, vanadium, zirconium and mixtures of these metals with others, which are not normally considered to be solutions of deuterium in a metal lattice.

25 f) "deuterium" shall mean the isotope of hydrogen having one proton and one neutron in its nucleus, which can be provided in the gaseous state (from 0.1 bar to 100 bar, preferably from 1 to 10 bar) or a result of electrolyzing a solution of D₂O or other deuterium-containing electrolyte.

g) "cold fusion" shall mean the fusion of two deuterium atoms into an atomic structure of an element of a higher molecular weight under temperatures of from about 0° to about 1000°C such as from about 50° to about 750°C and preferably from about 250° to about 750°C.

5 h) "internal" alphas shall refer to alphas that are the product of a cold fusion reaction;

i) "external" alphas or alphas "externally" supplied shall mean alphas which are provided by other than the fusion of two deuterium atoms.

It is believed, though not meant to be a limitation on the present invention,
10 that the mechanism includes the initiation by interaction of an alpha particle with a deuterium in an inelastic collision. An elastic collision could be viewed as a glancing blow or a near miss of the particles in which the particles involved in this kind of collision scatter (or "bounce") as a result. If the collision is inelastic, that is, if the kinetic energy of the alpha particle (two protons plus two neutrons) is
15 sufficient to overcome the alpha-deuterium Coulomb barrier, the addition of the proton and neutron of the deuterium nucleus may form a compound nucleus of lithium-6 (three protons plus three neutrons). This compound nucleus could decay in one of several ways, but residual kinetic energy of the compound nucleus will keep the ${}^6\text{Li}$ moving rapidly in the channel toward another deuterium
20 atom. When the ${}^6\text{Li}$ strikes a deuterium atom, it forms a new compound nucleus of ${}^8\text{Be}$ (four protons plus four neutrons). ${}^8\text{Be}$, being an unstable nucleus, will decay to two alpha particles. These two alpha particles have a total of 23.6 Mev kinetic energy. The alphas will fly apart from each other due to the repulsion of their positive charges and ultimately come to rest after losing their
25 kinetic energy (i.e., converting it into heat). The alphas may fly apart sideways in the channel, dislocating heavy atoms on both sides, or may find new channels in other directions. Alternately, one alpha may exit the channel while the other continues deeper in the channel. In either case, one incident alpha particle from an external source will have produced two alpha particles as a

result of a stepwise fusion of itself and two deuterium nuclei. No protons, neutrons, tritium or helium are produced, except possibly from a small amount of side reactions. The alphas ultimately come to rest after losing their kinetic energy (i.e., converting it into heat), pick up two electrons each, and become helium-4
5 atoms.

Alpha particles, when impacting substances with highly ordered lattices, like metals, may find a line of least resistance in a row of interstitial spaces of the lattice and travel somewhat freely and to significant depth as if travelling in a tube or channel, losing energy primarily to electrons in a sort of "friction" like
10 manner.

The deuterium can be in any form, such as a high-pressure chamber or concentrated in the interstitial spaces of a channeling material having a highly ordered lattice structure or the like.

The present invention, without abandoning the combination of deuterium
15 and alpha source alone, prefers the placement of deuterium (e.g., hydrogen atoms having primarily deuterium therein) in the interstitial spaces of a channeling material having a highly ordered lattice structure. The channeling material can be thought of as a sponge capable of absorbing and/or adsorbing the deuterium. This placement (by adsorption and/or absorption) causes the hydrogen to be in
20 such a configuration that rows of hydrogen atoms (in any of its isotopic forms, which include deuterium) will occur, and these hydrogen atoms can be visualized as lying in the "channels" of interstitial spaces of channeling material. The use of channeling materials having long channels is desired. Such materials can thus contain large amounts of hydrogen and deuterium atoms therein. The channel
25 length of a crystalline material can be assumed to be essentially the same as the grain size of the material.

The channel length should be at least an average of 2 to 50 microns, with from 2 to 25,000 microns or even higher being more desired and from 50 to 25,000 being preferred. Although materials having higher average lengths are

preferred, they are usually more difficult to form and, thereby incur an economic restraint on their availability. In most instances, metal channeling materials can be readily formed which provide channel lengths averaging from about 50 to 2,000 microns or greater in length. In addition, channeling material can be a non-metal, such as carbon in the form of nanotubes and deuterides, as described above.

The nuclear fusion reaction of interest is initiated by an incident alpha particle derived from an external source. The alpha source is normally placed within about 10 centimeters (preferably less than 7 cm and more preferably less than 3 cm) of a deuterium containing channeling material. The alpha particles that are emitted from the source impinge onto and into the channel material. When an alpha particle of sufficient energy enters a channel of the channeling material, essentially lined up with the channel axis, it will proceed until it encounters one deuterium atom and then another. An alpha particle may travel to 50 microns in a metal, past 20,000 to 200,000 metal atoms, and a comparable number of deuterium atoms. Channel-containing materials include metals such as palladium, platinum, titanium, magnesium, scandium, nickel, yttrium, vanadium, erbium, holmium, lutetium, thulium, tantalum, their alloys, deuterides (as defined herein), carbon nanotubes, and other alloys that absorb relatively large quantities of hydrogen. (Alloys that absorb large quantities of hydrogen are suggested as storage media; these include $\text{Ti}_5\text{Fe}_4\text{Ni}$, TiFe , Ti_5Cr_9 , LaNi_5 , CaNi_5 , Ba_7Cu_3 , K_2Zn , K_3Zn , TiV , TiMnV mixtures, TiMn_2 mixtures, ZrCo mixtures, NiMn mixtures, and ZrTiVNi mixtures. The preferred channel containing materials are palladium and titanium. It is preferred that the metal grains are well annealed rather than being cold worked. Such preferred channel-containing materials have longer channel configurations.

Each of these elements or alloys has its own pressure-temperature equilibrium, which will determine the temperature and pressure optimum for fusion operation. Some systems will accumulate high proportions of deuterium

at atmospheric pressure, while others require much higher pressures to achieve a deuterium-rich content suitable for fusion reaction. High pressure operation can confer advantages such as better thermal conductivity to a heat sink and faster shutdown in case of opening a safety valve. The preferred pressure
5 range of deuterium is between 1 and 10 bar (1 bar = 1 atmosphere pressure = 14.7 pounds per square inch), but fusion can be accomplished at lower pressures. Pressures above 10 bar are advantageous under some circumstances, such as when the channeling material does not absorb enough deuterium at lower pressures to reasonably fill its channels. The absorption of
10 hydrogen by metal channeling materials is discussed in "Hydrogen in Metals I and II" eds. G. Alefeld and J. Volkl, Springer-Verlag, Berlin 1978, the teachings of which are incorporated herein in its entirety by reference.

Other materials, such as deuterides of aluminum, barium, calcium, cerium, chromium, gadolinium, hafnium, lanthanum, lithium, magnesium,
15 manganese, nickel, niobium (columbium), potassium, sodium, strontium, titanium, thorium, uranium, vanadium, zirconium and the like, which are not normally considered to be solutions of deuterium in a metal also have rows of deuterium so arranged that alpha particles may impact first one, then another deuterium atom in a space surrounded by the heavy atoms to induce the fusion
20 reaction described.

The fusion reaction is also capable of being generated under certain conditions when it occurs on the surface of a metal like platinum, osmium, iridium, ruthenium, rhenium or nickel or between layers of a layer-containing material, like graphite (as contrasted with a one-dimensional channel-containing
25 material) which can adsorb or absorb or otherwise contain large quantities of deuterium and may be bounded on only one side by solid. In this case, the channel may be visualized as two-dimensional rather than one-dimensional. The uses of such surface fusion reactions include production of heat and light. In order to obtain light emission, the alpha multiplication ability of the fusion

reaction can be utilized to eject many alphas from the material surface to bombard a phosphor comprising material or the like.

It is preferred to conduct the present process using a channel material rather than the surface material in most applications as the alpha particles derived from an external source and the alpha particles internally generated are more readily contained for propagation of the reaction.

Additional fusion reactions may follow the first one because of the production of two alpha particles for each initiator alpha from an external source. Two alphas (internally generated alphas) are produced from every deuterium fusion. Although these alpha particles will fly apart from each other with great speed because of the repulsion of their positive charges, they do not always provide an alpha for fusion of additional deuterium. The alphas may fly apart sideways in the channel, dislocating heavy atoms on both sides, or may find new channels in other directions. Alternately, one alpha may exit the channel while the other continues deeper in the channel. In any case, one incident alpha particle will have produced two alpha particles as a result of a stepwise fusion of itself and two deuterium nuclei. No protons, neutrons, tritium or helium-3 are produced, except possibly from a small amount of side reactions. The alphas ultimately come to rest after losing their kinetic energy (i.e., converting it into heat), pick up two electrons each, and become helium-4 atoms. However, a fusion does not normally result from each internally generated alpha. Thus, a propagation factor (PF), as used herein and in the appended claims, defines the average number of fusions produced immediately after a given alpha particle induces a fusion. The PF is defined as two if every fusion results in two more fusions. Such a high propagation factor is not to be expected as a matter of course, for the following reasons:

1) Some of the alphas escape the channel without encountering deuterium nuclei.

2) Some of the alphas or the intermediate lithium-6 collide with the walls of the channel and are de-energized by collision with heavy atoms rather than deuterium.

3) The channels may be too short to contain many deuterium atoms
5 because the metal grains are cold-worked rather than well annealed.

4) The lithium-6 produced from the alpha and the first deuterium may decay to smaller nuclei before hitting a second deuterium.

5) Deuterium is consumed during the reaction, and if it is not replenished, or if the deuterium concentration (i.e. pressure) is low to begin with, the likelihood
10 of fusion reactions is diminished.

When alpha particles are diverted from continuing the chain reaction, the PF will drop from two to a lower value. For example, if the alphas are trapped by collisions with channel walls or are blocked by channel ends 60% of the time, the remaining 40% of reactions which are fruitful can provide only 0.8 fusions per
15 initiating alpha [= 2 x (100% - 60%)]. The equation relating PF (within the PF range of from 0 to 1) to total fusions per initiating alpha is: Total Fusions = 1 + [PF/(1 - PF)]. A comparison of the total number of fusions resulting from different propagation factors with respect to each initiating alpha is shown in Table 1. If the fusion reaction described occurs to any extent, the propagation factor will be
20 greater than zero, and has a maximum theoretical PF of 2. The PF needs only get close to 1.0 to yield a multiple of alpha particles, each with 11.8 Mev of energy, for each initiation event.

Table 1
Total Fusions (including initiation) at Different Propagation Factors

| Propagation Factor (PF) | Total Fusions |
|-------------------------|----------------------------|
| 0 | 1 (initiation fusion only) |
| 0.5 | 2 |
| 0.6 | 2.5 |
| 0.7 | 3.33 |
| 0.8 | 5 |
| 0.9 | 10 |
| 0.95 | 20 |
| 0.99 | 100 |
| 0.999 | 1000 |
| 1.0 or greater | limited by deuterium |

5 The PF of the deuterium channel material system should be maintained between about 0.5 and 1, preferably between 0.7 and 1, and most preferably between 0.9 and 1 to sustain the nuclear fusion process and produce the greatest amount of heat therefrom.

10 The propagation factor can be increased by making the channels longer and by filling them with more deuterium. The PF can also be increased by capturing some or all of the alphas that would otherwise exit the channel material, i.e., by positioning a second surface close to a first surface so that alphas escaping one surface will bombard the other. This may be achieved, for example, by folding a foil and bringing two surfaces into proximity such that alphas may

15 cross the separation without significant loss of energy or by supporting several wires or rods or other shapes in proximity to one another. If these are to be the electrodes in an electrolysis, one or more of the separate shapes may be

connected to the negative electrode to produce deuterium atoms and molecules. Since the range of alphas in a gas, such as air, is on the order of 7 centimeters for an 8 Mev alpha, the separation in deuterium gas should be less than this, preferably less than 3 cm, and variation in distance could be used as a control technique.

Any known alpha particle source can be used as the external source for initiating the present cold fusion process. The alpha source can be of any known and reliable form, such as an alpha source comprising about 1 microcurie or less of americium-241, to initiate the fusion chain reaction. One microcurie of any radioactive element undergoes 37,000 disintegrations per second. Although not all of these will be fruitful as initiation events, the effective ones will be multiplied by the propagation factor (PF) to propagate the reaction. Controlling the amount of external alphas initiating the deuterium fusion at any time during propagation can, thus, control the continued propagation of fusion within the system. Illustrative examples of other alpha sources that are useful as external sources are: radium, radon gas, uranium or any of the elements having an atomic number of at least that of bismuth (at. no.=83) which decay by alpha emission, especially polonium and plutonium-238. However, the large amount of Pu-238 alpha emitter such as is used in radioisotope thermal generators (RTG's) is expensive and its temperature is only minimally controllable and, therefore, is not preferred.

An alternative alpha source where a neutron flux is available consists of a non-radioactive element such as lithium, beryllium or boron on or near the channel-containing surface. When impacted by neutrons, these elements will emit alpha particles that can initiate fusion. The alternative alpha source should be placed within about 10 cm of a channeling material containing deuterium.

The alpha source may also be added to an electrolyte as a metal salt. Deuterium can be produced and supplied by electrolysis. By the addition of the metal source to the electrolyte, one can bring the alpha emitter to the channeling

material surface to cause alphas to initiate fusion. If radon gas (a nonelectrolyte) is dissolved in the electrolyte, some will enter the deuterium gas phase, from which it will be even more effective in bombarding the channeling material. Radon can also be added directly to the deuterium gas phase.

5 The alpha source or alternative alpha source may also be alloyed with, or mixed with, or imbedded in, the channeling material to provide alphas where they will have a higher probability of initiating deuterium fusion.

 The distance between the external source of alpha particles and the deuterium containing channel material, including surface layer material, should be
10 from 0.01 to 10 cm., preferably less than about 7 cm., more preferably less than about 3 cm. and most preferably less than about 1 cm.

 As stated above, the present invention is directed to a method of generating energy by fusion of deuterium comprising the initiation of the fusion by subjecting deuterium to alpha radiation from an external source and subsequently
15 controlling the propagation rate of the reaction by controlling the amount of alpha radiation that leads to further deuterium fusion.

 The deuterium is preferably located within channels of a channel containing material or on the surface of a material, as described above. The deuterium can be provided directly as a gas or produced in situ from electrolysis
20 of D_2O . Another way to provide the D_2 for fusion is to add an active metal, such as lithium, sodium, potassium, rubidium, cesium, aluminum, calcium, strontium, barium or magnesium to a small quantity of D_2O . The addition can be controlled by mechanical injectors or by tipping the container to bring the metal and D_2O together. The deuterium can be impregnated into the channels by conventional
25 techniques such as incipient impregnation and the like. Deuterium may be the sole material infused into the channeling lattice or it may be mixed with an inert material, such as protium or other gaseous element. It is preferred that deuterium be the sole or at least the major material in the channel unless this mixing is utilized as a control method. Modifications, such as those utilized in

known vacuum techniques, can be used here. For example, a channeling material and an alpha source may be located together under reduced pressure in one arm of a glass or metal tube, separated by a valve from another arm which contains deuterium under some higher pressure. When the valve is opened, 5 deuterium enters the arm with the alpha source and channeling material to enable fusion to occur. Alternately, the channeling material and alpha source could be accompanied by some active metal in a glass or metal tube, under reduced pressure and separated by a valve from the second arm, which contains deuterium oxide. When this valve is opened, deuterium oxide, in a gaseous or 10 liquid form will transfer to the first arm and react with the active metal, producing deuterium gas, which will enable fusion to occur. Such apparatus can be sealed from the outside atmosphere and develop temperatures higher than those achievable when operating at atmospheric pressure in aqueous solution.

Control of the fusion reaction may be visualized as control of the PF over 15 a preferred range of about 0.7 to 1. The total number of fusions per externally supplied alpha rises dramatically as the PF approaches 1. One mode of controlling the PF over this range is to provide optimum conditions for a high PF by using material with long channels through which alphas can traverse and deuterium can fill and then perform operations which reduce the PF to a desired 20 value. If the channels are short, as in most cold worked or cold drawn materials, alpha particles will suffer a change in course on crossing grain boundaries, slip planes and other distortions in the lattice. Such a change in course is normally not gradual and easy, but, instead, is more likely to skew the path of the alpha and make it collide with a heavy atom. The alpha may lose so 25 much energy before entering another channel that it is unable to overcome the Coulomb barrier of a deuterium nucleus.

The mechanical condition and heat treatment of the lattice of the channeling material will preferably lead to long channels by annealing to develop relatively large uniform grains and considerable channel length. The

temperature and time for heat treatment for each channeling material will vary as is known by those skilled in the art. Such parties are aware of how to remove cold work stress (the first stage of annealing, which is not sufficient to grow large grains), and further, to determine temperatures and times needed to grow
5 larger grains (a second stage of heat treatment). Non-metals (e.g., deuterides) may be caused to develop long channels by slow crystallization and grain growth techniques rather than by annealing techniques. For control purposes, the crystal (grain) growth may be deliberately arrested to limit the maximum propagation factor available. Suitable purity is required to minimize dislocations and other
10 imperfections in the channeling lattice, but some impurities are without effect. This is the first control method.

A second method useful in controlling the fusion reaction is varying the pressure of deuterium or its amount in the channeling material. There is a minimum concentration of deuterium below which the fusion reactions are so
15 improbable as to be almost undetectable, and while this lower level must be exceeded, varying the deuterium pressure is not fast enough for rapid control near $PF = 1.0$. A pressure relief valve is a useful safety device to limit the duration of high temperature excursions.

A third control technique comprises a system with a PF that has been
20 increased by bringing two or more surfaces of a channeling material into close proximity. Reversing the process by which the PF was increased in the first place can reduce the PF of such a system. This control method reduces the PF by moving the surfaces apart, or turning them so that their projection upon each other is reduced.

25 A fourth control technique is to insert an alpha barrier between two surfaces, which are in close proximity and function to produce a high PF. The barrier may be liquid, e.g., the electrolyte in a cell which puts deuterium gas in contact with a channeling material. When the cell is constructed so that two or more surfaces are in proximity while submerged in electrolyte, the PF will be

small because the liquid is an effective barrier for alphas. Deuterium gas may be evolved in such a way that the gas does not escape but, instead, forces the liquid down. The channeling material will not be merely coated with bubbles, but some of the proximate surfaces will be exposed, allowing a mutual
5 irradiation with alphas through a gaseous phase. As the PF increases toward 1.0, heat is developed, the temperature rises and the gas would expand, pushing the electrolyte down farther, exposing more surface to inter-surface alpha bombardment, with more fusions resulting. This could lead to a runaway reaction. Control would be exerted by applying a higher external pressure to the liquid to
10 force it back between the surfaces or by releasing or pumping off some of the deuterium to allow the liquid to surge back between the proximate surfaces. This method of reducing the number of fusion reactions is much faster than merely reducing the external pressure of deuterium, because the deuterium absorbed in the channeling material requires time to diffuse out.

15 Another way to reduce the PF is to insert a solid alpha barrier, such as a metal film or plate or wires (e.g., a woven or non-woven mesh), between the proximate surfaces. As alphas strike the barrier and are removed from the chain reaction, the PF decreases and the reaction slows down.

Controlling the number of externally supplied alphas can be used to
20 provide a more linear control of the fusion reaction. The externally supplied alphas are multiplied by internal propagation to yield the totality of fusions. If the PF is maintained below 1, as would be preferred for stable reactor operation, the number of fusions and, therefore, the total amount of heat produced is proportional to the number of externally supplied alphas.

25 Rather than using a large amount of expensive alpha emitter material to produce all the heat energy needed to operate a thermoelectric generator (RTG), a very small, and therefore cheaper and safer, amount of radioactive material may be used along with a channeling material such as palladium with deuterium, with added control features to produce heat which will be converted into electricity by

thermoelectric junctions. For example, a typical RTG contains 11 kilograms of PuO_2 in 1 inch by 1 inch cylindrical ceramic pellets, surrounded by a thermoelectric pile which generates direct current as a result of the temperature gradient. In the improved invention, smaller diameter cylinders (1/8 inch, or
5 less), containing 1/64 (or less) of the original amount of alpha emitter, are surrounded by palladium (or other channeling material) tubes and supplied with deuterium gas when needed to produce temperatures of 200 to 400 degrees C or higher. The tube materials absorb deuterium and fusion is initiated by the plutonium alphas. If the PF is brought up to 0.97, even more heat will be
10 developed than in the original RTG, although the number of alphas involved is smaller: the fusion alphas have 11.8 Mev energy versus 5.5 Mev for the plutonium alphas. Appropriate control devices may be added for even more flexibility.

Those who are very familiar with nuclear processes will quickly grasp the novelty of the present invention, and the accuracy of the description in this
15 specification and claims. However, several developments considered in the formation of the present process will be discussed herein below to further aid in describing the invention. These descriptions are merely for purposes of illustrating the present invention and are not meant to be a limitation of the present invention as defined by the claims appended hereto.

20 The first description to be clarified relates to that of temperature. Temperature is related to the average kinetic energy of a particle by the equation: $E \text{ (in Mev)} = kT = 8.61 \times 10^{-11} T$. From this equation, energy of 0.1 Mev corresponds to a little over a billion degrees Kelvin. The conclusion is that a moderately energetic alpha particle has a very high temperature, which is well into
25 the range needed to provide for fusion.

The second description relates to "Coulomb barrier". The Coulomb barrier, the repulsion energy of two positively charged nuclei, is so much greater than the energies and temperatures involved in ordinary chemical transformations that it is usually appropriate to regard the Coulomb barrier as

simply insurmountable, even without quantitative calculations. However, cold fusion as has been explained herein involves alpha particles with an equivalent temperature higher than a billion degrees C. The Coulomb barrier can be estimated from the literature for repulsion between two hydrogen nuclei at 5 E-13 cm (a distance suitable for fusion) to be ~0.28 Mev. This implies that the alpha-D barrier (two positives times one positive) would be ~0.56 Mev and the Li-D barrier (three positives times one positive) would be ~0.84 Mev while other estimates of the alpha-D barrier are as low as 0.1 Mev and of the Li-D barrier as low as 0.15 Mev.

It can be seen that the Coulomb barrier can be surmounted. In such cases one considers the mass balance of each of the nuclear reactions to be considered. The mass of an alpha particle is 4.0026 atomic mass units (amu), and the mass of a deuterium is 2.0140 amu. Their sum is 6.0166 amu, which is greater than the mass of lithium-6 (6.01512 amu). This first reaction is thus exothermic, and since the alpha particle had to possess some kinetic energy to surmount the Coulomb barrier, there is a considerable excess of mass and energy available to be converted into kinetic energy (heat). Lithium-6 has several levels of nuclear excitation above the ground state which could temporarily accommodate some of this energy. One effect of a nucleus being in an excited state is to develop a larger radius, meaning that it would develop a greater cross-section and thus be more likely to undergo a collision with some other nucleus. If the excited lithium-6 collides inelastically with another deuterium, the total mass is at least 8.0306 amu, which is significantly more than the mass of beryllium-8 (8.0053 amu). Thus, the second reaction is also exothermic. Beryllium-8 rapidly decays to two alpha particles and all of the excess mass is converted into kinetic energy of these alphas, which are propelled apart with a total of 23.6 Mev. No other particles are produced.

It should be noted that the high energy of the nascent alpha particles is enough to surmount the Coulomb barrier of light elements. Therefore, in the

interest of reducing the possibility of producing new elements, which might be radioactive, by transmutation, heavier elements are preferred for holding deuterium for fusion where the possibility of human exposure or disposal of radioactive materials is required.

5 The following should be noted in carrying out the present invention:

A. Alpha source is a radioactive element such as radium, americium, polonium, plutonium, or any of the elements heavier than bismuth, which are radioactive by alpha decay. These elements should be placed within about 10
10 centimeters of a channeling or surface adsorbing material having the deuterium therein and/or thereon. Alternately, the alpha source can be radon in solution of electrolyte or in D₂ gas.

B. Alternatively, alpha sources that are useful where there is a significant neutron flux, (e.g., at or near uranium fission reactors) can be lithium,
15 beryllium or boron or other elements which produce alphas upon irradiation with neutrons. Such elements are preferably placed within about 10 cm of a channeling material. Boric acid solution is used as a neutron shield around uranium reactors; the alphas produced are trapped in H₂O.

C. Channeling materials include such metals (and alloys of these
20 metals) as palladium, platinum, titanium, magnesium, scandium, nickel, yttrium, vanadium, erbium, holmium, lutetium, thulium, tantalum, their alloys, deuterides (as defined herein), carbon nanotubes, and other alloys that absorb relatively large quantities of hydrogen including Ti₅Fe₄Ni, TiFe, Ti₅Cr₉, LaNi₅, CaNi₅, Ba₇Cu₃, K₂Zn, K₃Zn, TiV, TiMnV mixtures, TiMn₂ mixtures, ZrCo mixtures, NiMn
25 mixtures, and ZrTiVNi mixtures. Surface layer materials (two-dimensional channels) such as platinum, osmium, iridium, ruthenium, rhenium or nickel or a layer-containing material like graphite (as contrasted with a one-dimensional channel-containing material) can adsorb or absorb or otherwise contain large quantities of deuterium.

E. Deuterides useful in containing and providing the deuterium required by the present invention can be formed from metals such as aluminum, barium, calcium, cerium, chromium, gadolinium, hafnium, lanthanum, lithium, magnesium, manganese, nickel, niobium (columbium), potassium, sodium, strontium, titanium, thorium, uranium, vanadium, zirconium and mixtures of these metals with others, but are not normally considered to be solutions of deuterium in a metal lattice

F. Deuterium, whether provided in the gaseous state (from 0.1 bar to 100 bar, preferably from 1 to 10 bar) or a result of electrolyzing a solution of D₂O or other deuterium-containing electrolyte, is a necessary component of the present fusion reaction. Without a channeling material present, the pressure required for deuterium fusion is on the order of from 100 to 2000 bar or more with from 100 to 1000 bar normally providing sufficient deuterium concentration.

G. A heat generating device consisting of an alpha source, an alpha-multiplying channeling material, deuterium gas and a control device consisting of a) an interposable alpha barrier or b) a control method in which the space between channeling elements is varied or c) a method for exposing more or less of the alpha source to the channeling material can be made in sizes from about two cubic inches to many cubic meters.

H. Method of generating heat (for electric power, transportation, residential heating, etc.) is by multiplying alpha particles, using deuterium and a channeling material through:

- a) a process for generating two alphas from one alpha + two deuteriums;
- b) a process for creating excited lithium-6 (alpha + channeling material + deuterium); or
- c) a process for creating excited beryllium-8 (lithium-6 + channeling material + deuterium).

I. Method of increasing propagation factor is by providing two or more surfaces within a distance capable of causing mutual alpha irradiation to

increase the number of fusions: face-to-face plates or other surfaces, tube geometry (circular cylinder, or oval, rectangular or other cross section); and by varying spacing to control the PF of the system to within a range suitable to propagate and sustain the fusion reaction.

5 J. Method of increasing propagation factor is by providing longer channels for the reaction through proper heat treatment of the channel material.

K. Method of reducing propagation factor for control of reaction is by placing a material suitable as an alpha barrier between surfaces that are irradiating each other, such as metal in the form of plates, rods, tubes, films,
10 wires, liquid and the like

L. A thermoelectric generator can be made utilizing a minimal amount of radioactive alpha emitter (such as radium, polonium, plutonium-238 or americium-241), a channeling material such as palladium, and an atmosphere of deuterium with a control element.

15 M. A light-emitting device composed of a central wire or foil with a small amount of alpha emitter alloyed, imbedded or coated thereon, surrounded by wires or foils of channeling or layer materials, in an atmosphere of deuterium, all in a sealed transparent tube coated internally with a phosphor.

N. A method of controlling the total heat output of a cold fusion reactor
20 which varies the number of external alpha particles supplied to the channeling material which contains deuterium by varying the exposure of the external alpha source. The external alpha source may be inserted more fully into the reactor environment to provide more alphas or withdrawn to reduce the rate of heat production. The external alpha source may be covered with or hidden by an
25 alpha barrier, more or less, to hinder or allow more alpha particles to impact the channeling material in a controlled manner.

O. A heat generating device consisting of an alpha source and deuterium gas at a pressure from 100 to 2000 bar or more (preferably from 100 to 1000 bar), without a channeling material, with a pressure control to vary the

PF of the system and a heat transfer or collection arrangement to use the heat beneficially.

It shall be understood that any range of numbers recited in the specification or claims, such as that representing a particular set of properties,
5 units of measure, conditions, physical states or percentages, is intended to literally incorporate expressly herein by reference or otherwise, any number falling within such range, including any subset of numbers within any range so recited.

10 EXAMPLE:

A common approach among previous researchers in the field has been to look for excess heat generated by deuterium fusion during an ongoing electrolytic process which generates deuterium from D_2O . The electrolytic
15 process itself generates a significant amount of heat (on the order of a watt or more). When the number of initiating events is infrequent (as, for example, when neutrons strike lithium-6 from the electrolyte to produce an initiating alpha particle), which is the case under all human-inhabitable conditions, significant heat production by such a fusion process requires a high propagation factor
20 (PF). To get only about a third of a watt from fusion of deuterium would require 100 billion fusions per second, which is very many times more than the neutron flux in background radiation. A high propagation factor requires, among other things, a high loading of deuterium within a channeling material. Electrolytic loading to 0.7 atoms of deuterium per atom of palladium is relatively easy, but
25 significant heat is not usually observed until the deuterium loading exceeds 0.85 D atoms per Pd atom. This is because the PF is not high enough to cause many deuterium fusions at the lower deuterium loading.

The example below utilizes a more sensitive way to detect the fusion of deuterium by the process of alpha multiplication by loading a piece of palladium with deuterium by electrolysis in D₂O, withdrawing the palladium from solution, drying it and then exposing it to alpha particles. A piece of palladium will not
5 contain all the alpha particles resulting from fusion, and some will exit the palladium, in all directions, toward as well as away from the alpha source. These alpha particles can be observed and counted. If the PF is relatively small, the chain reaction will die off before a significant number of alpha particles traverse the entire thickness of the palladium. In such a case, alpha
10 particles may still be observed exiting the palladium toward the alpha source. Detection of these alpha particles requires the alpha source to be aimed away from the detector, as described in the example below.

A palladium cathode (99.95% pure, 7.0032 grams, 21 x 12 x 2
15 millimeters, annealed at 1000 C for 1 hour) was paired with a palladium anode (99.9+% pure, 15 x 25 millimeters, 0.5142 grams, not annealed) in a solution consisting of 0.1056 grams of lithium carbonate in 9.625 grams of deuterium oxide (99.9% pure) and electrolyzed over a period of 47 hours with currents from 0.1 to 0.42 amperes (ending with a 2.5 hour period at 0.350 amperes).
20 The temperature of the cell ranged from 27 C to 59 C and was dependent on the ambient temperature (19.5 C) and the power input from the electrolytic process. The voltage applied to the cell ranged from 4.62 to 9.82 volts; it was supplied from a rechargeable lead-acid battery through a controllable constant voltage power supply. To obtain higher current, higher voltage was required;
25 higher temperature of solution typically increased the current for the same voltage. The minimum charge theoretically required for saturation of this palladium with 1.0 deuterium per palladium atom is 6350 coulombs (= amperes x seconds); the actual amount supplied was 22,636 coulombs. The weight

measurement at the end of the electrolysis showed a weight gain corresponding to 0.79 atoms of D per palladium atom.

5 A measurement in triplicate of alpha particles from fusion in palladium was set up with an alpha source (about 0.1 microcurie of Americium-241, supported on aluminum, giving 82,200 counts per minute (cpm) when directed toward a Geiger counter at a distance of 0.4 centimeters). When the alpha source was directed away from the Geiger counter and moved to 0.6 centimeters, the reading fell to 57.8 +/- 3.7 cpm.; this was only slightly above
10 the background of 47.2 +/- 2.8 cpm. When the deuterated palladium described above was placed about 0.7 centimeters from the alpha source (therefore 1.3 centimeters from the Geiger counter), the detected radiation increased to 96.3 +/- 7.5 cpm. The excess, 38.5 +/- 11.2 represents a possible exit flux of alpha particles from deuterium fusion. Higher deuterium loading than the 0.79 used in
15 this experiment, with appropriate safety precautions, would give a higher PF and would make this effect more dramatic.

20

5

Claims:

1. A method of generating energy by cold fusion comprising
 - a) contacting deuterium atoms contained in a deuterium rich system with alpha
 - 10 particles to cause fusion of said deuterium; and
 - b) controlling the total energy output and propagation of the deuterium fusion by varying the number of alpha particles externally supplied to the deuterium atoms while maintaining said system with a propagation factor (PF) of from 0.5 to 1.
- 15 2. The method of Claim 1 wherein the deuterium is contained in channels of a material selected from palladium, platinum, titanium, magnesium, scandium, nickel, yttrium, vanadium, erbium, holmium, lutetium, thulium, tantalum, their alloys, deuterides (as defined herein), carbon nanotubes and other alloys that absorb relatively large quantities of hydrogen, including $\text{Ti}_5\text{Fe}_4\text{Ni}$, TiFe , Ti_5Cr_9 ,
- 20 LaNi_5 , CaNi_5 , Ba_7Cu_3 , K_2Zn , K_3Zn , TiV , TiMnV mixtures, TiMn_2 mixtures, ZrCo mixtures, NiMn mixtures, and ZrTiVNi mixtures.
3. The method of Claim 1 wherein the deuterium is contained on the surface of materials selected from platinum, osmium, iridium, ruthenium and rhenium,
- 25 nickel, graphite and the like.
4. The method of Claim 1, 2 or 3 wherein the deuterium is in a gaseous state under pressure of from 0.1 bar to 100 bar.
- 30 5. The method of Claim 1, 2 or 3 wherein the deuterium is a product of electrolyzing a solution comprising a deuterium-containing electrolyte.

5 6. The method of Claim 1, 2 or 3 wherein the deuterium is derived from deuterides of metals such as aluminum, barium, calcium, cerium, chromium, gadolinium, hafnium, lanthanum, lithium, magnesium, manganese, nickel, niobium (columbium), potassium, sodium, strontium, titanium, thorium, uranium, vanadium, zirconium and mixtures of these metals with others.

10

7. The method of Claim 4 wherein the external source of alpha particles is a radioactive alpha decay element selected from radium, americium, polonium, plutonium, or at least one element having an atomic number of at least 83.

15

8. The method of Claim 5 wherein the external source of alpha particles is a radioactive alpha decay element selected from radium, americium, polonium, plutonium, or at least one element having an atomic number of at least 83.

20

9. The method of Claim 6 wherein the external source of alpha particles is a radioactive alpha decay element selected from radium, americium, polonium, plutonium, or at least one element having an atomic number of at least 83.

25

10. The method of Claim 4 wherein the external source of alpha particles comprises lithium, beryllium or boron in combination with a neutron flux sufficient to provide alpha particles to sustain said fusion.

30

11. The method of Claim 5 wherein the external source of alpha particles comprises lithium, beryllium or boron in combination with a neutron flux sufficient to provide alpha particles to sustain said fusion.

12. The method of Claim 6 wherein the external source of alpha particles comprises lithium, beryllium or boron in combination with a neutron flux sufficient to provide alpha particles to sustain said fusion.

5

13. The method of Claim 2 or 3 wherein the deuterium containing system has a PF of from 0.7 to 1 and the external source of alpha particles is within 10 cm of the deuterium rich system.

10

14. The method of claim 2 wherein the material is subjected to heating or crystallizing or both to produce material having an average channel length at least 2 microns long.

15

15. The method of Claim 1 wherein the deuterium is in the gaseous state under pressure of from 100 bar to 2000 bar.

20

16. An apparatus capable of providing energy by cold fusion reaction comprising a deuterium containing system capable of maintaining a PF of from 0.5 to 1, an external source of alpha radiation that is proximate to said deuterium containing system, a means of regulating the dosage of alpha particles directed to said deuterium to sustain the fusion reaction and a means of collecting the energy generated by said deuterium fusion reaction.

25

17. The apparatus of Claim 16 wherein the deuterium is contained in channels of a material selected from palladium, platinum, titanium, magnesium, scandium, nickel, yttrium, vanadium, erbium, holmium, lutetium, thulium, tantalum, their alloys, deuterides (as defined herein), carbon nanotubes, and other alloys that absorb relatively large quantities of hydrogen, including $\text{Ti}_5\text{Fe}_4\text{Ni}$, TiFe , Ti_5Cr_9 , LaNi_5 , CaNi_5 , Ba_7Cu_3 , K_2Zn , K_3Zn , TiV , TiMnV mixtures, TiMn_2 mixtures, ZrCo mixtures, NiMn mixtures, and ZrTiVNi mixtures.

30

5 18. The apparatus of Claim 16 wherein the deuterium is contained on the surface of materials selected from platinum, osmium, iridium, ruthenium, rhodium, nickel, graphite or mixtures thereof.

19. The apparatus of Claim 16, 17 or 18 wherein the deuterium is in the
10 gaseous state under pressure of from 0.1 bar to 100 bar.

20. The apparatus of Claim 16, 17 or 18 wherein the deuterium is a product of electrolyzing a solution comprising a deuterium-containing electrolyte.

15 21. The apparatus of Claim 16, 17 or 18 wherein the deuterium is derived from deuterides of metals such as aluminum, barium, calcium, cerium, chromium, gadolinium, hafnium, lanthanum, lithium, magnesium, manganese, nickel, niobium (columbium), potassium, sodium, strontium, titanium, thorium, uranium, vanadium, zirconium and mixtures of these metals with others.

20 22. The apparatus of Claim 16 wherein the external source of alpha particles is a radioactive alpha decay element selected from radium, americium, polonium, plutonium, or at least one element having an atomic number of at least 83.

25 23. The apparatus of Claim 17 wherein the external source of alpha particles is a radioactive alpha decay element selected from radium, americium, polonium, plutonium, or at least one element having an atomic number of at least 83.

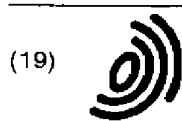
24. The apparatus of Claim 18 wherein the external source of alpha particles is
30 a radioactive alpha decay element selected from radium, americium, polonium, plutonium, or at least one element having an atomic number of at least 83.

5 25. The apparatus of Claim 16 wherein the external source of alpha particles comprises lithium, beryllium or boron in combination with a neutron flux sufficient to provide alpha particles to sustain said fusion.

10 26. The apparatus of Claim 17 wherein the external source of alpha particles comprises lithium, beryllium or boron in combination with a neutron flux sufficient to provide alpha particles to sustain said fusion.

15 27. The apparatus of Claim 18 wherein the external source of alpha particles comprises lithium, beryllium or boron in combination with a neutron flux sufficient to provide alpha particles to sustain said fusion.

28. The apparatus of Claim 17 or 18 wherein the deuterium containing system has a PF of from about 0.7 to 1 and the external source of alpha particles is within 10 cm of the deuterium containing system.



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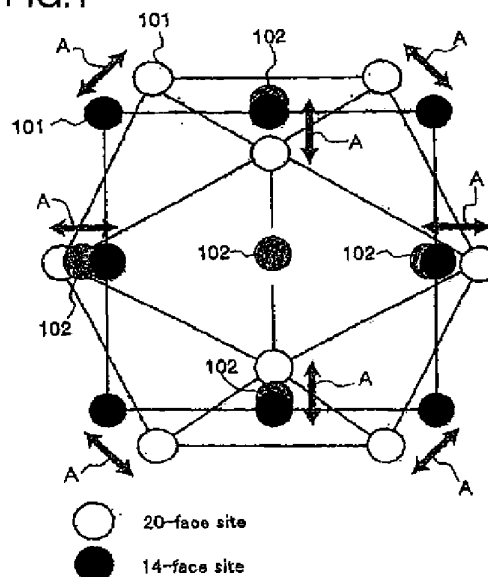
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(54) **HYDROGEN CONDENSATE AND METHOD OF GENERATING HEAT THEREWITH**

(57) The present invention provides a method of generating heat using a hydrogen condensate. The hydrogen condensate comprises a plurality of metal atoms contained in a metal nano-ultrafine particle and a plurality of hydrogen isotope atoms solid-dissolved among the plurality of metal atoms. At least two of the plurality of hydrogen isotope atoms are condensed so that the inter-atomic nuclear distance between two hydrogen isotope atoms is smaller than or equal to the internuclear spacing of a molecule consisting of two hydrogen isotope atoms. The heat generation method comprises applying energy to the hydrogen condensate and generating heat by causing the at least two hydrogen isotope atoms to react with each other due to the energy.

FIG.1



Description

TECHNICAL FIELD

[0001] The present invention relates to a hydrogen condensate such that a plurality of hydrogen isotope atoms are solid-dissolved among a plurality of metal atoms, and a method of generating heat using the hydrogen condensate.

[0002] The present invention makes it possible to produce new energy which is safe and whose resource is guaranteed to be inexhaustible and which is therefore desired by the human race, and helium gas which is useful and whose abundance is very small. Further, the present invention provides an immeasurable contribution to development of new science and technology in a wide variety of fields, such as energy science and technology, material science and technology, refrigerant technology, aeronautical engineering and the like, and further, any activities for the continuation of the human race, and the conservation of the Earth's environment.

BACKGROUND ART

[0003] Conventional energy sources include fossil fuels, water power, nuclear energy, wind power, hydrogen, solar light, and the like. However, when these energy sources are used, serious problems inevitably arise, including exhaustion of resources, environmental destruction, inefficiency and the like. Therefore, there are concerns over the use of these energy sources for the future. On the other hand, ultrahigh temperature nuclear fusion has been proposed as a new energy source, however, its practical use is still distant.

[0004] Recently, methods of utilizing electrolysis using palladium electrodes (Pd) have been developed as an energy source. However, for most of them, there are doubts about the possibility of the practical use as an energy source.

[0005] For example, a method of utilizing a Double Structure (DS) cathode, with which the present inventors attained the only success, has a poor level of heat generation efficiency, and its industrialization was actually impossible (see Yoshiaki Arata, M. J. A, and Yue-Chang Zhang, Formation of condensed metallic deuterium lattice and nuclear fusion, Proceedings of the Japan Academy, the Japan Academy, March 28, 2002, Vol. 78, Ser. B, No. 3, p. 57-62).

[0006] The DS-cathode used in the above-described method is, for example, a DS-cathode using Pd black ultrafine particles (see WO95/35574) or a DS-cathode using metal nanoparticles (see Japanese Laid-Open Publication No. 2002-105609).

[0007] Further, the present inventors made an attempt to apply ultrasonic energy to a bulk (metal bulk) or a foil (metal foil) implanted with deuterium oxide (D_2O) to generate heat. However, the efficiency of the heat generation is poor, so that there are doubts about

the industrialization of this technique (see Yoshiaki Arata, M. J. A, and Yue-Chang Zhang, Nuclear fusion reacted inside metals by intense sonoplasma effect, Proceedings of the Japan Academy, the Japan Academy, March 28, 2002, Vol. 78, Ser. B, No. 3, p. 63-68).

[0008] The present invention is provided to solve the above-described problems. An object of the present invention is to provide: (1) a hydrogen condensate in which a larger quantity of hydrogen isotope atoms are solid-dissolved among metal atoms than in conventional techniques; and (2) a method of generating heat using the hydrogen condensate.

DISCLOSURE OF THE INVENTION

[0009] The present invention was completed based on the finding that the hydrogen condensate of the present invention has a function or behavior different from conventional bulk (metal bulk) or foil (metal foil) and is useful as a material for a nuclear fusion reaction. In other words, the present invention was completed by novel and innovative exploration, selection and combination of various conditions using the hydrogen condensate of the present invention, but not modification of conditions for conventional bulk or foil.

[0010] The present inventors disproved a conventional established theory after we had keenly and diligently studied for over half a century. According to the conventional established theory, when deuterium is solid-dissolved in palladium particles, which are known to be the best to solid-dissolve hydrogen, the number of deuterium atoms/the number of palladium atoms is 70 to 80% and cannot exceed 100%. To our surprise, we achieved a pressurizing effect corresponding to several hundred millions of atmospheric pressure to hydrogen gas by applying a practical level of pressure (about 0.3 to about 100 atmospheric pressure), and utilized a hydrogen condensate which was produced under a practical level of pressure for a nuclear fusion reaction. The present invention was completed based on our achievements and perspectives. Energy which is generated using the heat generation method of the present invention is referred to as "ARATA ENERGY".

[0011] A method of the present invention is a method of generating heat using a hydrogen condensate. The hydrogen condensate comprises a metal nano-ultrafine particle containing a plurality of metal atoms and a plurality of hydrogen isotope atoms solid-dissolved among the plurality of metal atoms, and at least two of the plurality of hydrogen isotope atoms are condensed so that an inter-atomic nuclear distance between the two hydrogen isotope atoms is smaller than or equal to an inter-nuclear spacing of a molecule consisting of the two hydrogen isotope atoms. The heat generation method comprises applying energy to the hydrogen condensate, and generating heat by causing the at least two hydrogen isotope atoms to react with each other due to the energy. Thereby, the above-described object is

achieved.

[0012] The plurality of metal atoms may be metal atoms of at least one species selected from the group consisting of palladium, titanium, zirconium, silver, iron, nickel, copper, and zinc.

[0013] Another method of the present invention is a method of generating heat using a hydrogen condensate. The hydrogen condensate comprises a metal alloy composite containing a plurality of metal atoms and a plurality of hydrogen isotope atoms solid-dissolved among the plurality of metal atoms, and at least two of the plurality of hydrogen isotope atoms are condensed so that an inter-atomic nuclear distance between the two hydrogen isotope atoms is smaller than or equal to an internuclear spacing of a molecule consisting of the two hydrogen isotope atoms. The heat generation method comprises applying energy to the hydrogen condensate, and generating heat by causing the at least two hydrogen isotope atoms to react with each other due to the energy. Thereby, the above-described object is achieved.

[0014] The energy may be generated based on at least one of ultrasonic wave, strong magnetic field, high pressure, laser, laser explosive flux-compression, high-density electron beam, high-density current, discharge, and chemical reaction.

[0015] In the step of generating heat, the at least two hydrogen isotope atoms are reacted with each other to generate a helium molecule in addition to the heat.

[0016] A hydrogen condensate of the present invention comprises a metal nano-ultrafine particle containing a plurality of metal atoms, and a plurality of hydrogen isotope atoms solid-dissolved among the plurality of metal atoms. At least two of the plurality of hydrogen isotope atoms are condensed so that an inter-atomic nuclear distance between the two hydrogen isotope atoms is smaller than or equal to an internuclear spacing of a molecule consisting of the two hydrogen isotope atoms. Thereby, the above-described object is achieved.

[0017] The plurality of metal atoms may be metal atoms of at least one species selected from the group consisting of palladium, titanium, zirconium, silver, iron, nickel, copper, and zinc.

[0018] Another hydrogen condensate of the present invention comprises a metal alloy composite containing a plurality of metal atoms, and a plurality of hydrogen isotope atoms solid-dissolved among the plurality of metal atoms. At least two of the plurality of hydrogen isotope atoms are condensed so that an inter-atomic nuclear distance between the two hydrogen isotope atoms is smaller than or equal to an internuclear spacing of a molecule consisting of the two hydrogen isotope atoms. Thereby, the above-described object is achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019]

Figure 1 is a diagram schematically showing an exemplary structure of a hydrogen condensate 100.

Figure 2 is a diagram showing an exemplary structure of a heat generation apparatus 200.

Figure 3 is a diagram showing changes over time in heat generated by solid-dissolving a mixture gas of deuterium gas and helium gas into a ZrO_2 -Pd particle, and changes over time in the internal pressure of a reaction furnace 201.

Figure 4 is a diagram showing comparison between heat generation before applying an ultrasonic wave to the ultrahigh-density deuterated nanoparticle and heat generation during application of ultrasonic wave.

Figure 5 is a diagram showing comparison of an ultrahigh-density deuterated nanoparticle sample produced by solid-dissolving deuterium atoms into a ZrO_2 -Pd particle between before and after applying the ultrasonic wave to the sample (before and after a nuclear fusion reaction).

Figure 6A is a diagram showing the result of analysis of gas generated when the ultrasonic wave was applied to an ultrahigh-density deuterated nanoparticle produced by solid-dissolving deuterium atoms into a ZrO_2 -Pd particle (during a nuclear fusion reaction).

Figure 6B is a diagram showing the result of analysis of gas generated after the ultrasonic wave was applied to a ultrahigh-density deuterated nanoparticle produced by solid-dissolving deuterium atoms into a ZrO_2 -Pd particle (after a nuclear fusion reaction).

Figure 6C is a diagram showing spectra of M4.

Figure 7 is a diagram schematically showing an exemplary structure of a hydrogen condensate 300.

Figure 8 is a diagram showing changes over time in heat generated by solid-dissolving deuterium gas into a Zr_3NiO -Pd particle, and changes over time in the internal pressure of the reaction furnace 201.

Figure 9 is a diagram showing that it is more difficult for deuterium atoms to be solid-dissolved in a Zr_3NiO -Pd particle when a mixture gas of deuterium gas and helium gas is used than when deuterium gas is used.

Figure 10 is a diagram showing the result of analysis of gas generated when the ultrasonic wave was applied to a deuterium condensate produced by solid-dissolving deuterium atoms into a Zr_3NiO -Pd particle (during a nuclear fusion reaction).

Figure 11 is a diagram showing that the quantity of helium generated by applying the ultrasonic wave to a deuterium condensate produced by solid-dissolving deuterium atoms into a Zr_3NiO -Pd particle is larger than the quantity of helium generated by applying the ultrasonic wave to a deuterium condensate produced by solid-dissolving deuterium atoms into a ZrO_2 -Pd particle.

BEST MODE FOR CARRYING OUT THE INVENTION

(Definition of terms)

[0020] Hereinafter, terms used herein will be defined.

[0021] "Metal nano-ultrafine particle": a metal nano-ultrafine particle means both "a metal nano-ultrafine particle and a group thereof" and "a surface layer corresponding to two-dimensional metal nano-ultrafine particles".

[0022] The metal nano-ultrafine particle (spherical shape) and the surface layer (circular shape) corresponding to two-dimensional metal nano-ultrafine particles have an average diameter which is calculated from a lattice size composed of at least 13 metal atoms. The average diameter is 5 nm at the maximum when the metal nano-ultrafine particles are buried, and 15 nm at the maximum when the metal nano-ultrafine particles are isolated. The metal nano-ultrafine particles include at least one metal selected from the group consisting of metals, such as palladium, titanium, zirconium, silver and the like. Note that, when the metal nano-ultrafine particles include two or more metals, they can be used in the form of mixture or coexistence or in the form of alloy in which these metal atoms are mixed or coexist.

[0023] When material is repeatedly subdivided into a certain critical size or less, the properties of the material suddenly change (Materials Transaction, JIM, Vol. 35, No. 9, pp. 563-575, 1994). Such a sudden change in material properties is recognized as a phenomenon that elasticity emerges in the bond between atoms of the material. For example, in the case of a lattice composed of four atoms, the phenomenon appears as if a non-elastic wooden lattice changes to a spring lattice. In the present invention, a metal particle or a metal crystal lattice and a metal surface layer whose physical properties are suddenly changed due to ultrafine subdivision are used as a material which is significantly effective for production of an ultrahigh-density deuterated nanoparticle (i.e., the above-described metal nano-ultrafine particle or surface layer corresponding to two-dimensional metal nano-ultrafine particles).

[0024] The metal nano-ultrafine particle can be pro-

duced using a method of oxidizing an amorphous alloy. For example, ZrO_2 -Pd having an average diameter of about 5 nm can be produced by oxidizing an amorphous alloy $Zr_{65}Pd_{35}$. The details of the method are described in Japanese Laid-Open Publication No. 2002-105609. Alternatively, the metal nano-ultrafine particle can be prepared using a vapor deposition method. The details of the method are described in "Materials Transaction, JIM, Vol. 35" (described above).

[0025] The metal nano-ultrafine particles may be buried in a support in a state that allows the particles to be separated from one another without contacting one another ("buried type" particles), or may be distributed in a liquid, a gas, a substrate or the like in a state that allows the particles to be separated from one another without contacting one another ("isolated type" particles).

[0026] The "buried type" particle has an average diameter in the range from a lattice size composed of at least 13 metal atoms to a maximum of 5 nm. The "isolated type" particle has an average diameter in the range from a lattice size composed of at least 13 metal atoms to a maximum of 15 nm. Note that the metal nano-ultrafine particle and the surface layer corresponding to the two-dimensional metal nano-ultrafine particles can be provided or commercialized singly as a material for a nuclear fusion reaction.

[0027] "Ultrahigh-density deuterated nanoparticle": an ultrahigh-density deuterated nanoparticle means both "an ultrahigh-density deuterated nanoparticle and a group thereof" and "an ultrahigh-density deuterated surface layer corresponding to two-dimensional ultrahigh-density deuterated nanoparticles". By using the ultrahigh-density deuterated nanoparticle and the surface layer corresponding to two-dimensional ultrahigh-density deuterated nanoparticles as hosts, it is possible to solid-dissolve deuterium atoms to an atom number ratio (the number of deuterium atoms/metal atoms) of 200% or more. In the present invention, for example, deuterium is caused to be absorbed into a buried-type metal nano-ultrafine particle having an average diameter of 5 nm or less under pressure. When the pressure is 10 atmospheric pressure or less, deuterium atoms can be solid-dissolved to an atom number ratio of 250% or more. When the pressure is 100 atmospheric pressure, deuterium atoms can be solid-dissolved to an atom number ratio of about 300%. Thus, an ultrahigh-density deuterium condensate can be formed, in which deuterium atoms are localized in the metal crystal lattice. As a result, an ultrahigh-density deuterated nanoparticle can be obtained. The formation of the deuterium condensate is performed in order to reduce the nuclear distance between two deuterium atoms to 0.6 Å or less which permits nuclear fusion. In this case, it is roughly estimated that the deuterium condensate has a pressurizing effect corresponding to deuterium gas to which several hundred millions of atmospheric pressure is applied (exactly speaking, in the case of an atom number ratio of 400%).

Commercially available deuterium can be used. The ultrahigh-density deuterated nanoparticle and a group thereof and the ultrahigh-density deuterated surface layer corresponding to the two-dimensional metal nano-ultrafine particles can be provided or commercialized singly as a material for a nuclear fusion reaction.

[0028] "Energy": energy means both impact energy and stationary energy. A means or an energy source which applies load energy to the ultrahigh-density deuterated nanoparticle and a group thereof and the ultrahigh-density deuterated surface layer corresponding to the two-dimensional metal nano-ultrafine particles, includes ultrasonic wave, strong magnetic field, high pressure, laser, laser explosive flux-compression, high-density electron beam, high-density current, discharge, chemical reaction, and the like. These energies can be used singly or in combination. Note that, when ultrasonic wave is used, a transfer medium for transferring the energy to a nuclear fusion reaction material is required, such as, for example, D₂O (commercially available), H₂O or the like. The energy to be applied needs to have intensity or quantity which can induce or cause a nuclear fusion reaction, such as 300 Watt and 19 kHz for an ultrasonic wave.

[0029] Hereinafter, embodiments of the present invention will be described with reference to the accompanying drawings.

1. Structure of hydrogen condensate 100

[0030] Figure 1 schematically shows an exemplary structure of a hydrogen condensate 100.

[0031] The hydrogen condensate 100 comprises a metal nano-ultrafine particle (host) and a plurality of hydrogen isotope atoms (guests) 102 which are solid-dissolved in a plurality of metal atoms 101 contained in the metal nano-ultrafine particle.

[0032] A larger quantity of hydrogen isotope atoms can be dissolved in the metal nano-ultrafine particle than in a metal particle (bulk metal particle) which is larger than the metal nano-ultrafine particle. This is because the bond between metal atoms in the metal nano-ultrafine particle is more elastic than the bond between metal atoms in the bulk metal particle, and therefore, a pressure applied to the metal nano-ultrafine particle and the hydrogen isotope atom in order to solid-dissolve the hydrogen isotope atom is lower than a pressure applied to the bulk metal particle and the hydrogen isotope atom in order to solid-dissolve the hydrogen isotope atom.

[0033] In Figure 1, an open circle indicates a 20-facesite of a metal atom, a closed circle indicates a 14-face site, and arrow A indicates elasticity of the bond between metal atoms in the metal nano-ultrafine particle.

[0034] Thus, the phenomenon that the bond between metal atoms in the metal nano-ultrafine particle has elasticity is based on the principle that when a material is subdivided into its specific critical size or less, a phys-

ical property thereof changes suddenly, so that elasticity emerges in the bond between atoms.

[0035] By using the above-described metal nano-ultrafine particle as a host, it is possible to cause hydrogen isotope atoms to be included in the hydrogen condensate to an atom number ratio (the number of hydrogen isotope atoms/the number of metal atoms) of 200% or more.

[0036] The quantity of hydrogen isotope atoms which can be contained in the hydrogen condensate depends on the magnitude of pressure applied to the metal nano-ultrafine particle and the hydrogen isotope atoms. For example, when the applied pressure is 10 times atmospheric pressure, hydrogen isotope atoms can be solid-dissolved in the metal nano-ultrafine particle to an atom number ratio of 250% or more. When the applied pressure is 100 times atmospheric pressure, hydrogen isotope atoms can be solid-dissolved in the metal nano-ultrafine particle to an atom number ratio of 300% or more. The plurality of hydrogen isotope atoms solid-dissolved in the metal nano-ultrafine particle exist as hydrogen condensates (local condensates) condensed in a metal lattice of the metal nano-ultrafine particle.

[0037] As described above, a larger number of hydrogen isotope atoms per unit particle can be solid-dissolved in the metal nano-ultrafine particle than in bulk metal particles. Therefore, the distance between hydrogen isotope atoms solid-dissolved in the metal nano-ultrafine particle is smaller than the distance between hydrogen isotope atoms solid-dissolved in the bulk metal particle. As a result, it is possible to apply a lower level of energy to the hydrogen condensate to react the hydrogen isotope atoms than that to a particle comprising a bulk metal particle and a plurality of hydrogen isotope atoms.

[0038] The hydrogen condensate needs to contain at least two hydrogen isotope atoms. This is because the two hydrogen isotope atoms are caused to react with each other. A combination of the two hydrogen isotope atoms which react with each other in the hydrogen condensate may be a combination of the same hydrogen isotope atoms or of different hydrogen isotope atoms. The at least two hydrogen isotope atoms contained in the hydrogen condensate are condensed so that the inter-atomic nuclear distance between the two hydrogen isotope atoms is smaller than or equal to the internuclear spacing of a molecule consisting of the two hydrogen isotope atoms. As the number of hydrogen isotope atoms contained in the hydrogen condensate is increased, the hydrogen condensate is more useful as a fuel for a nuclear fusion reaction.

1.1 Guest of hydrogen condensate

[0039] Combinations of two hydrogen isotope atoms which are usable as guests of hydrogen condensate are, for example, a combination of a deuterium atom (D) and a deuterium atom (D), a combination of a deuterium

atom (D) and a tritium atom (T), a combination of a deuterium atom (D) and a hydrogen atom (H), a combination of a tritium atom (T) and a hydrogen atom (H), and a combination of a tritium atom (T) and a tritium atom (T). In consideration of the cost efficiency, ease of control, safety and cleanliness of the nuclear fusion reaction, the order of preference is the combination of a deuterium atom (D) and a deuterium atom (D), the combination of a deuterium atom (D) and a hydrogen atom (H), the combination of a tritium atom (T) and a hydrogen atom (H), and the combination of a deuterium atom (D) and a tritium atom (T). The combination of a deuterium atom (D) and a deuterium atom (D) is especially recommendable.

[0040] The atom number ratios of deuterium atom (D) / hydrogen atom (H), tritium atom (T) / hydrogen atom (H) and deuterium atom (D) / tritium atom (T) are arbitrarily determined. Two or more of the above-mentioned combinations of atoms contained in a hydrogen condensate may coexist, may exist in a mixed state, or may be mixed.

[0041] A hydrogen condensate is formed by aggregating or condensating hydrogen isotope atoms on a surface layer or in the inside of the host described below. In order to attain the aggregation or condensation, the two isotope atoms need to be aggregated such that the inter-atomic nuclear distance between the two isotope atoms contained in the host is within the internuclear spacing of a molecule consisting of the two hydrogen isotope atoms (e.g., D₂, DH, TH, DT, etc.). Specifically, for example, when a plurality of hydrogen isotope atoms are contained in a hydrogen condensate, the deuterium atoms need to be packed, captured and adjusted in the host such that the distance between two atoms of D-D, the distance between three atoms of D-D-D, and the distance between four atoms of D-D-D-D are each within the internuclear spacing of a D molecule (D₂) (e.g., 0.074 nm or less).

1.2 Host of hydrogen condensate

[0042] The host is used as a vessel or capsule for capturing and adjusting or forcibly packing the combinations of two or more hydrogen isotopes within the internuclear spacing of the molecule. The space or room which is retained on a surface layer or in the inside of the host as the capsule is preferably of the nanometer order (e.g., the average diameter of the space regarded as the sphere is preferably about 0.002 to about 200 nm, or preferably about 0.005 to about 50 nm). The number of captured hydrogen isotopes/hydrogen condensate needs to be at least two. It is considered that as the number of captured hydrogen isotopes is larger, the performance or efficiency of the hydrogen condensate as a fuel for nuclear fusion reaction is higher. It is desirable that the outer wall of the above-mentioned capsule or vessel as the host is elastic at the atomic or molecular level.

1.3 Atomic structure as host

[0043] Atomic structures which are nano-order ultrafine particles obtained by subdividing metal crystals in the form of lattice and have an average diameter in the range of one lattice unit size to a maximum of 50 nm are usable as hosts. Metal host candidates are, for example, known metals forming known lattice crystals, such as body centered cubic lattice, face-centered cubic lattice, hexagonal close-packed structure and the like (e.g., palladium, titanium, zirconium, silver, iron, nickel, copper, zinc, etc.), and a combination of two or more of these metals.

1.4 Molecular structure as host

[0044] Inorganic compounds and aggregations thereof or crystal structures which have a shape of lattice, cube, rectangular parallelepiped, quadrangular column, hexagonal column, honeycomb, other polygonal columns, cylinder, tube, sphere, polymorphism, amorphous or the like as a shape of a unit as a vessel or capsule for capturing and adjusting hydrogen isotope atoms are usable as hosts. For example, aggregations or crystal structures of oxides and hydroxides of tin, zinc, iron, zirconium, titanium and the like, and carbon nanotube and the like are host candidates.

[0045] Single-stranded, double-stranded, or branched polymeric organic compounds having such a length that can capture and adjust the above-mentioned combinations of hydrogen isotopes (e.g., D and D, D and H, T and H, D and T, etc.) as host by winding are host candidates (e.g., protein, DNA, RNA, starch, polymeric hydrocarbon, derivatives thereof, polymeric compounds for synthetic fibers, etc.), for example. Single-stranded, double-stranded, or branched polymeric organic compounds having such a space or room that can capture and adjust the guest material by burying it in a surface layer or in the inside thereof having a primary, secondary or tertiary structure are host candidates, for example. Organic compounds (e.g., cyclodextrin, fullerene, etc.) which can capture and adjust the guest material in a surface layer or in the inside thereof having a cylindrical or spherical molecular structure in the inside or in a surface layer thereof are host candidates, for example.

1.5 Preparation of hydrogen condensate

[0046] Air existing in the host material is removed by vacuum and/or heating, and then a guest is added to the host material to cause them to coexist or mix them. Then, the resultant material is allowed to stand and/or lowered in temperature such that it is not frozen, and pressurized under 10 to 100 atmospheric pressure. Thus, the guest is captured or solid-dissolved into the host, whereby a hydrogen condensate can be formed.

1.6 Form of hydrogen condensate provided

[0047] The hydrogen condensate can be commercialized in the form of a solid, such as film, powder, capsule or the like, or a liquid.

2. Method of generating heat using hydrogen condensate 100

[0048] Figure 2 shows an exemplary structure of a heat generation apparatus 200. The heat generation apparatus 200 is used to produce the hydrogen condensate 100 by solid-dissolving hydrogen isotope atoms 102 among a plurality of metal atoms 101 contained in a metal nano-ultrafine particle. The heat generation apparatus 200 is also used to generate heat using the hydrogen condensate 100.

[0049] The heat generation apparatus 200 comprises a reaction furnace 201, a vacuum exhaust port 202, a gas injection port 203 for injecting hydrogen isotope gas, a transfer medium injection port 204, a gas outlet 205, an ultrasonic wave generation means 206, and an ultrasonic vibrator 207. The heat generation apparatus 200 can be applied to power generation means, battery, heating a room, cooling a room and the like, and can be implemented as a small-size apparatus or a portable apparatus for these applications, which cannot be practically used in conventional technology.

[0050] The reaction furnace 201 accommodates the hydrogen condensate 100. Air is exhausted via the vacuum exhaust port 202 from the reaction furnace 201. A medium (D_2O , H_2O , etc.) for transferring ultrasonic wave to the hydrogen condensate 100 is injected via the transfer medium injection port 204. High-temperature and high-pressure gas and helium gas are removed via the gas outlet 205. The ultrasonic generation means 206 generates an ultrasonic wave. The ultrasonic wave vibrator 207 transfers the ultrasonic wave to the ultrasonic wave transfer medium.

[0051] In the example of Figure 2, ultrasonic wave energy is applied to the hydrogen condensate 100. The energy causes at least two of a plurality of deuterium atoms solid-dissolved in the hydrogen condensate 100 to react with each other, thereby making it possible to generate heat and helium gas.

[0052] Note that the energy applied to the hydrogen condensate 100 is not limited to the ultrasonic wave energy. Examples of the energy applied to the hydrogen condensate 100 include any impact energy and any stationary energy. For example, the energy applied to the hydrogen condensate 100 may be energy which is generated based on at least one of ultrasonic wave, strong magnetic field, high pressure, laser, laser explosive flux-compression, high-density electron beam, high-density current, discharge, and chemical reaction. Two or more of these energies may be used in combination.

[0053] Note that the structure of the heat generation apparatus 200 is not limited to that shown in Figure 2.

Figure 2 only illustrates an exemplary structure of the heat generation apparatus 200. An apparatus having any arbitrary structure can be used instead of the heat generation apparatus 200 as long as it can achieve a function equivalent to that of the heat generation apparatus 200. The heat generation apparatus 200 may function as an apparatus for generating heat using a nuclear fusion reaction material. In this case, the heat generation apparatus 200 preferably comprises a nuclear fusion reaction furnace which accommodates a nuclear fusion reaction material, a means of controlling a nuclear fusion reaction, a means of applying impact energy and/or stationary energy to the nuclear fusion reaction material to induce or cause a nuclear fusion reaction, a means of removing generated heat, and a means of collecting generated helium. Each means included in the heat generation apparatus 200 can be added or omitted as required and as appropriate.

<Example 1>

[0054] A buried-type metal nano-ultrafine particle (ZrO_2 -Pd particle) was produced by using zirconia (ZrO_2) as a support and burying ZrO_2 -Pd having an average diameter of about 5 nm into the support. The metal nano-ultrafine particle (ZrO_2 -Pd particle) was placed in the reaction furnace 201, and thereafter, deuterium gas (D_2 gas) was injected into the reaction furnace 201. A pressure was applied to the metal nano-ultrafine particle (ZrO_2 -Pd particle) and the deuterium gas (D_2 gas) to cause the metal nano-ultrafine particle (ZrO_2 -Pd particle) to absorb deuterium atoms, thereby preparing a nuclear fusion reaction material (ultrahigh-density deuterated nanoparticle). Thereafter, impact energy created by activating the ultrasonic wave vibrator 207 was applied via an ultrasonic wave transfer medium (D_2O) to the ultrahigh-density deuterated nanoparticle, thereby causing a nuclear fusion reaction.

[0055] Hereinafter, a procedure for operating the heat generation apparatus 200 will be described.

[0056] Operation I: a ZrO_2 -Pd particle (3.5 g) was accommodated in the reaction furnace 201. The reaction furnace 201 was evacuated to a high level of vacuum (10^{-7} Torr) by heating the reaction furnace 201 at $150^\circ C$ while removing air via the vacuum exhaust port 202.

[0057] Operation II: deuterium gas (D_2 gas) was injected via the gas injection port 203 into the reaction furnace 201. The injection of deuterium gas (D_2 gas) was performed at a constant rate (20 cc/min). The internal pressure of the reaction furnace 201 was set to be about 10 times atmospheric pressure so that deuterium atoms were solid-dissolved into the ZrO_2 -Pd particle and a condensate was formed. As a result, an ultrahigh-density deuterated nanoparticle having an atom number ratio of 250% or more was obtained. Note that the quantity of solid-dissolved atoms was calculated based on the flow rate of the injected gas and a time required for the gas pressure in the reaction furnace to be increased.

[0058] The deuterium gas is solid-dissolved into the ultrahigh-density deuterated nanoparticle in the form of deuterium atoms, but not in the form of deuterium molecules.

[0059] Note that the gas injected via the gas injection port 203 is not limited to deuterium gas. A mixture of deuterium gas and gas of another hydrogen isotope (e. g., H₂ gas) may be injected. A mixture of gas of a hydrogen isotope and gas of another hydrogen isotope may be injected. A mixture of deuterium gas and another different species of gas may be injected. For example, a mixture of deuterium gas and helium gas increases the solid-dissolution rate of deuterium atoms (Figure 9), and therefore, this mixture gas is preferably used. However, a mixture of deuterium gas and neon inhibits solid-dissolution of deuterium atoms, and therefore, this mixture gas is not preferably used. As the different species of gas used in the mixture gas, a material having an atomic diameter similar to that of a deuterium atom is considered to be desirable.

[0060] Figure 3 shows changes over time in heat generated by solid-dissolving a mixture gas of deuterium gas and helium gas into the ZrO₂-Pd particle, and changes over time in the internal pressure of the reaction furnace 201. In Figure 3, a vertical axis (left) represents temperature (°C), another vertical axis (right) represents the internal pressure (atm) of the reaction furnace 201, and the horizontal axis represents time (min).

[0061] When a mixture gas of deuterium gas and helium gas is solid-dissolved into the ZrO₂-Pd particle, the temperature of an outer wall surface of the reaction furnace 201 is increased up to a maximum of 45°C due to chemical reaction heat generated by the solid-dissolution. It takes 55 min to 60 min for the internal pressure of the reaction furnace 201 to reach 10 atm.

[0062] Note that the temperature of the outer wall surface of the reaction furnace 201 was measured. This is because the internal pressure of the reaction furnace 201 may be increased to a very high level, and in this case, the temperature of the inside of the reaction furnace 201 cannot be measured.

[0063] Operation III: the ultrasonic wave transfer medium 210 was injected via the transfer medium injection port 204 into the reaction furnace 201 so that the ultrasonic wave vibrator 207 was sufficiently immersed in the reaction furnace 201. Examples of the ultrasonic transfer medium 210 include water (H₂O), water vapor, and commercially available heavy water (D₂O).

[0064] Operation IV: ultrasonic wave energy was applied from an edge surface of the ultrasonic wave vibrator 207 via the ultrasonic wave transfer medium 210 to the ultrahigh-density deuterated nanoparticle.

[0065] The intensity of the ultrasonic wave is, for example, 300 watt and 19 kHz. Note that the intensity of the ultrasonic wave is not limited to 300 watt and 19 kHz as long as the intensity is sufficient that a plurality of deuterium atoms solid-dissolved in the ultrahigh-density deuterated nanoparticle react with one another.

[0066] As an element used in the nuclear fusion reaction, elements having an atomic number of 4 or less and an isotope thereof can be used. Taking ease of handling into consideration, preferably, deuterium (D) is used singly, or alternatively, a combination of deuterium (D) and hydrogen (H) or a combination of deuterium (D) and tritium (T) is used.

[0067] By applying energy to the ultrahigh-density deuterated nanoparticle, a plurality of deuterium atoms react with one another to generate heat and helium molecules. The reaction is represented by:



[0068] The reaction does not generate a neutron and is a mild nuclear fusion reaction, and therefore, is desirably better than a DD nuclear fusion reaction described below. Therefore, the ultrahigh-density deuterated nanoparticle of the present invention is recommended to be used for a nuclear fusion reaction in terms of the conservation of the environment. The well-known DD nuclear fusion reaction which causes a radical impact of deuterium atoms to generate T and neutrons is extremely dangerous, and therefore, is not desirable in terms of industrial applicability and conservation of the environment.

[0069] The reaction of deuterium generates high-temperature and high-pressure gas and helium gas in the reaction furnace 201. The high-temperature and high-pressure gas and the helium gas are removed via the gas outlet 205.

[0070] The high-temperature and high-pressure gas is, for example, transferred to a turbine generator, in which the gas is in turn used as a drive source for driving the turbine generator. The high-temperature and high-pressure gas is transferred to the turbine generator in the form of jet gas. Therefore, the generated heat can be used to drive the turbine generator without being converted to vapor or potential energy. Further, the generated heat can be used as alternative energy in place of water power, thermal power, wind power, coal, petroleum, nuclear power and the like, or clean energy which allows reproduction and conservation of the Earth's environment, in all fields.

[0071] Impurity gas which is mixed in helium generated in the reaction furnace 201 liquefies or solidifies at about 50 K. Therefore, by cooling the impurity gas at a cryogenic temperature to be liquefied or solidified, it is possible to remove the impurity gas from helium. As a result, it is possible to produce and collect helium gas in large quantities. Alternatively, helium can be collected by causing the impurity to be absorbed in a purification column. Helium produced according to the present invention can be used in well-known applications, such as welding protection gas, filling gas for aerostat, gas enclosed in a discharge tube, artificial air for diving, and the like. Since helium gas can be collected in large quantities,

lities and with low cost, development of novel applications of helium can be promoted.

[0072] Figure 4 shows the comparison between heat generation before applying ultrasonic wave to the ultrahigh-density deuterated nanoparticle and heat generation during application of ultrasonic wave. In Figure 4, the vertical axis represents temperature ($^{\circ}\text{C}$) and the horizontal axis represents time (min).

[0073] In Figure 4, a curve A shows changes overtime in heat generated when deuterium atoms are solid-dissolved in the $\text{ZrO}_2\text{-Pd}$ particle (before a nuclear fusion reaction), and a curve B shows changes over time in heat generated when the ultrasonic wave is applied to an ultrahigh-density deuterated nanoparticle produced by solid-dissolving deuterium atoms into the $\text{ZrO}_2\text{-Pd}$ particle (during a nuclear fusion reaction). Note that the temperature of the outer wall surface of the reaction furnace 201 was measured. This is because the temperature of the inside of the reaction furnace 201 is too high to be measured.

[0074] When deuterium atoms were solid-dissolved into the $\text{ZrO}_2\text{-Pd}$ particle, chemical reaction heat (about 40 kJ/mol) was generated, so that a slight increase in temperature was detected at the outer wall surface of the reaction furnace 201 (the curve A in Figure 4).

[0075] When the ultrasonic wave is applied to an ultrahigh-density deuterated nanoparticle produced by solid-dissolving deuterium atoms into the $\text{ZrO}_2\text{-Pd}$ particle (during a nuclear fusion reaction), the temperature of the outer wall surface of the reaction furnace 201 rapidly increased, so that specific temperature characteristics were observed (the curve B in Figure 4). The rapid increase in the temperature of the outer wall surface of the reaction furnace 201 indicates that a nuclear fusion reaction continued for about 10 minutes. Most of the heavy water (D_2O) which is the ultrasonic wave transfer medium 210 in the reaction furnace 201 was vaporized, and was decomposed into D_2 or D. The inside of the reaction furnace 201 is considered to have high temperature and high pressure, indicating a tremendous nuclear fusion reaction.

[0076] Figure 5 shows comparison of an ultrahigh-density deuterated nanoparticle sample produced by solid-dissolving deuterium atoms into the $\text{ZrO}_2\text{-Pd}$ particle before and after applying the ultrasonic wave to the sample (before and after a nuclear fusion reaction).

[0077] In Figure 5, [A] and [B] show the ultrahigh-density deuterated nanoparticle sample before applying the ultrasonic wave (before a nuclear fusion reaction), and [C] and [D] show the ultrahigh-density deuterated nanoparticle sample after applying the ultrasonic wave (before a nuclear fusion reaction).

[0078] As can be seen from [C] and [D] of Figure 5, zirconia (ZrO_2) contained in the ultrahigh-density deuterated nanoparticle is melted due to high temperature after application of the ultrasonic wave. The temperature of the inside of the reaction furnace 201 is too high to measure. However, since the melting point of zirconia

(ZrO_2) is about 1850°C , the temperature of the inside of the reaction furnace 201 is considered to be about 1850°C or more.

[0079] Based on the above-described finding, we determined that the resultant nuclear fusion reaction is $2\text{D} + 2\text{D} = 4\text{He} + \text{lattice energy (23.8 MeV)}$.

[0080] Note that, when the ultrasonic wave was applied (operations III and IV) to the ultrahigh-density deuterated nanoparticle produced by solid-dissolving deuterium atoms to an atom number ratio of less than 200% (operation II), it was confirmed that the heavy water (D_2O) which is the ultrasonic wave transfer medium 210 in the reaction furnace 201 was not vaporized and substantially remained in the reaction furnace 201.

[0081] Figure 6A shows the result of analysis of gas generated when the ultrasonic wave was applied to the ultrahigh-density deuterated nanoparticle produced by solid-dissolving deuterium atoms into the $\text{ZrO}_2\text{-Pd}$ particle (during a nuclear fusion reaction). In Figure 6A, the vertical axis represents pressure (ppm) and the horizontal axis represents time (sec). Gas generated in the reaction furnace 201 was analyzed using a Quadrupole Mass Spectrometer (QMS).

[0082] In Figure 6A, M2 indicates D, M3 indicates DH, and M4 indicates He. As can be seen, a nuclear fusion reaction caused deuterium atoms solid-dissolved in the ultrahigh-density deuterated nanoparticle to react with one another to generate a large quantity of helium (He) gas.

[0083] Figure 6B shows the result of analysis of gas generated after the ultrasonic wave was applied to the ultrahigh-density deuterated nanoparticle produced by solid-dissolving deuterium atoms into the $\text{ZrO}_2\text{-Pd}$ particle (after a nuclear fusion reaction). In Figure 6B, the vertical axis represents pressure (ppm) and the horizontal axis represents time (sec).

[0084] After the reaction, the sample was removed from the reaction furnace 201. The sample was heated at $1,300^{\circ}\text{C}$ in a sample container of the QMS. Gas thus generated was analyzed using the QMS.

[0085] In Figure 6B, M2 indicates D, M3 indicates DH, and M4 indicates D_2 . As can be seen, after the nuclear fusion reaction, substantially no He or D remained in the ultrahigh-density deuterated nanoparticle.

[0086] Figure 6C shows spectra of M4. In Figure 6C, the vertical axis represents an intensity of the spectra (10^{-9} A) and the horizontal axis represents elapsed time (min). As can be seen from Figure 6C, D_2 disappeared over time, while most He remained.

[0087] Worthy of special note with reference to Figures 6A, 6B and 6C is that the quantity of M4 (=He) produced during the nuclear fusion reaction (Figure 6A) was large by an order of magnitude or more, and most of the deuterium atoms solid-dissolved in the ultrahigh-density deuterated nanoparticle reacted with one another to generate helium gas. In contrast, substantially no He or D existed in the ultrahigh-density deuterated nanoparticle after the nuclear fusion reaction (Figure 6B).

[0088] As described above, a larger number of deuterium atoms per unit particle can be solid-dissolved in the metal nano-ultrafine particle than in bulk metal particles. Therefore, the distance between deuterium atoms solid-dissolved in the metal nano-ultrafine particle is smaller than the distance between deuterium atoms solid-dissolved in the bulk metal particle. As a result, it is possible to apply a lower level of energy to the ultra-high-density deuterated nanoparticle to cause a heat generation reaction at low temperature and for a long duration of time as compared to energy applied to a particle comprising the bulk metal particle and a plurality of deuterium atoms.

3. Structure of hydrogen condensate 300

[0089] Figure 7 schematically shows an exemplary structure of a hydrogen condensate 300.

[0090] The hydrogen condensate 300 comprises a zirconium-nickel alloy composite (host) and a plurality of hydrogen isotope atoms (guests) 302 solid-dissolved among a plurality of metal atoms 301 contained in the zirconium-nickel alloy composite. A larger quantity of hydrogen isotope atoms can be solid-dissolved in the zirconium-nickel alloy composite than in bulk metal particles. This is because the bond between metal atoms in the zirconium-nickel alloy composite is more elastic than the bond between metal atoms in the bulk metal particle, and therefore, a lower level of pressure needs to be applied to the zirconium-nickel alloy composite and hydrogen isotope atoms to solid-dissolve the hydrogen isotope atoms, than the level of pressure applied to the bulk metal particle and hydrogen isotope atoms to solid-dissolve the hydrogen isotope atoms.

[0091] In Figure 7, arrow B indicates the elasticity of the bond between metal atoms in the zirconium-nickel alloy composite.

[0092] The hydrogen condensate 300 comprises a Zr-Pd-Ni particle ($Zr_3NiO \cdot Pd$ particle) and a plurality of deuterium atoms solid-dissolved among a plurality of metal atoms contained in the Zr-Pd-Ni particle ($Zr_3NiO \cdot Pd$ particle), for example.

[0093] The details of a production method of the Zr-Pd-Ni particle are described in, for example, Japanese Patent Application No. 2003-340285 (filed on September 30, 2003).

[0094] Note that the hosts and/or guests described in 1.1 to 1.4 above can be used as the host and/or guest of the hydrogen condensate 300.

[0095] The zirconium-nickel alloy composite may be, for example, a $Zr_3NiO \cdot Pd$ particle or $Zr_4Ni_2O_x(0.3-1)$.

[0096] Note that metal alloy composites other than the zirconium-nickel alloy composite can be used. The hydrogen condensate 300 may comprise a metal alloy composite (host) and a plurality of hydrogen isotope atoms (guests) solid-dissolved among a plurality of metal atoms contained in the metal alloy composite. In this case, the plurality of metal atoms contained in the metal

alloy composite are at least two metal atoms selected from the metal group consisting of zirconium, titanium, nickel, palladium, magnesium, and boron. The metal alloy composite is, for example, an oxide of a metal alloy.

4. Method of generating heat using hydrogen condensate 300

[0097] As an apparatus for generating heat using the hydrogen condensate 300, the heat generation apparatus 200 of Figure 2 is used, for example. The heat generation apparatus 200 is used to produce the hydrogen condensate 300 by solid-dissolving hydrogen isotope atoms 302 among a plurality of metal atoms 301 contained in a zirconium-nickel alloy composite. The heat generation apparatus 200 is also used to generate heat using the hydrogen condensate 300.

[0098] By applying energy to the hydrogen condensate 300, a plurality of hydrogen isotope atoms react with one another to generate heat. For example, by applying energy to the hydrogen condensate 300 containing a plurality of deuterium atoms, the deuterium atoms react with one another to generate helium molecules as well as heat. The reaction is represented by:



[0099] The reaction does not generate a neutron and is a mild nuclear fusion reaction, and therefore, is desirably better than a DD nuclear fusion reaction described below. Therefore, the hydrogen condensate 300 of the present invention is recommended to be used for a nuclear fusion reaction in terms of the conservation of the environment. The well-known DD nuclear fusion reaction which causes a radical impact of deuterium atoms to generate T and neutrons is extremely dangerous, and therefore, is not desirable in terms of industrial applicability and conservation of the environment.

[0100] As described in 2. above, the reaction of deuterium generates high-temperature and high-pressure gas and helium gas in the reaction furnace 201.

<Example 2>

[0101] A zirconium-nickel alloy composite (including a $Zr_3NiO \cdot Pd$ particle, $Zr_4Ni_2O_x(0.3-1)$) was produced. The zirconium-nickel alloy composite was placed in the reaction furnace 201, and thereafter, deuterium gas (D_2 gas) was injected into the reaction furnace 201. A pressure was applied to the zirconium-nickel alloy composite and the deuterium gas (D_2 gas) to cause the zirconium-nickel alloy composite to absorb deuterium atoms, thereby preparing a nuclear fusion reaction material (ultra-high-density deuterated metal alloy). Thereafter, impact energy created by activating the ultrasonic wave vibrator 207 was applied via an ultrasonic wave transfer medium (D_2O) to the ultra-high-density deuterated metal

alloy, thereby causing a nuclear fusion reaction.

[0102] A procedure for operating the heat generation apparatus 300 is similar to that described in <Example 1> and will not be explained.

[0103] Figure 8 shows changes over time in heat generated by solid-dissolving deuterium gas into the Zr_3NiO -Pd particle, and changes over time in the internal pressure of the reaction furnace 201. In Figure 8, a vertical axis (left) represents temperature ($^{\circ}C$), another vertical axis (right) represents the internal pressure (atm) of the reaction furnace 201, and the horizontal axis represents time (min).

[0104] It takes 70 min or more for the internal pressure of the reaction furnace 201 to reach 10 atm. When a mixture gas of deuterium gas and helium gas is solid-dissolved into the ZrO_2 -Pd particle, it takes 55 min to 60 min for the internal pressure of the reaction furnace 201 to reach 10 atm (see Figure 3). Therefore, it will be understood that a larger number of deuterium atoms are solid-dissolved in the Zr_3NiO -Pd particle than in the ZrO_2 -Pd particle.

[0105] Figure 9 shows that it is more difficult for deuterium atoms to be solid-dissolved in the Zr_3NiO -Pd particle when a mixture gas of deuterium gas and helium gas is used than when deuterium gas is used. In Figure 9, a vertical axis (left) represents temperature ($^{\circ}C$), another vertical axis (right) represents the internal pressure (atm) of the reaction furnace 201, and the horizontal axis represents time (min).

[0106] A curve P^*_{He} indicates changes over time in the internal pressure of the reaction furnace 201 when a mixture gas of deuterium gas and helium gas is solid-dissolved into the Zr_3NiO -Pd particle. A curve P^* indicates changes over time in the internal pressure of the reaction furnace 201 when deuterium gas is solid-dissolved into the Zr_3NiO -Pd particle. The rising of the curve P^*_{He} is earlier than the rising of the curve P^* . Therefore, it will be understood that it is more difficult for deuterium atoms to be solid-dissolved in the Zr_3NiO -Pd particle when a mixture gas of deuterium gas and helium gas is used than when deuterium gas is used.

[0107] Figure 10 shows the result of analysis of gas generated when the ultrasonic wave was applied to the deuterium condensate produced by solid-dissolving deuterium atoms into the Zr_3NiO -Pd particle (during a nuclear fusion reaction). In Figure 10, the vertical axis represents pressure (ppm) and the horizontal axis represents time (sec). Gas generated in the reaction furnace 201 was analyzed using the QMS.

[0108] In Figure 10, M2 indicates D, M3 indicates DH, and M4 indicates He. As can be seen, a nuclear fusion reaction caused deuterium atoms solid-dissolved in the deuterium condensate to react with one another to generate a large quantity of helium (He) gas.

[0109] Figure 11 shows that the quantity of helium generated by applying the ultrasonic wave to the deuterium condensate produced by solid-dissolving deuterium atoms into the Zr_3NiO -Pd particle is larger than the

quantity of helium generated by applying the ultrasonic wave to the deuterium condensate produced by solid-dissolving deuterium atoms into the ZrO_2 -Pd particle. In Figure 11, the vertical axis represents 4He concentration (ppm). The length of a line A indicates the quantity of helium (2.45×10^4 ppm) generated by applying the ultrasonic wave to the deuterium condensate produced by solid-dissolving deuterium atoms into the ZrO_2 -Pd particle. The length of a line B indicates the quantity of helium (1.23×10^5 ppm to 1.6×10^5 ppm) generated by applying the ultrasonic wave to the deuterium condensate produced by solid-dissolving deuterium atoms into the Zr_3NiO -Pd particle.

[0110] As described above, a larger number of deuterium atoms per unit particle can be solid-dissolved in the zirconium-nickel alloy composite than in bulk metal particles. Therefore, the distance between deuterium atoms solid-dissolved in the zirconium-nickel alloy composite is smaller than the distance between deuterium atoms solid-dissolved in the bulk metal particle. As a result, it is possible to apply a lower level of energy to the ultrahigh-density deuterated zirconium-nickel alloy composite to cause a heat generation reaction at low temperature and for a long duration as compared to energy applied to a particle comprising the bulk metal particle and a plurality of deuterium atoms.

INDUSTRIAL APPLICABILITY

[0111] The present invention provides a hydrogen condensate useful as a fuel and a method of generating heat using the hydrogen condensate. The present invention makes it possible to produce energy which is safe and whose resource is guaranteed to be inexhaustible and which is therefore desired by the human race, and helium gas which is useful and whose abundance is very small. Further, the present invention provides an immeasurable contribution to development of new science and technology in a wide variety of fields, such as energy science and technology, material science and technology, refrigerant technology, aeronautical engineering and the like, and further, any activities for the continuation of the human race, and the conservation of the Earth's environment.

Claims

1. A method of generating heat using a hydrogen condensate,

wherein the hydrogen condensate comprises a metal nano-ultrafine particle containing a plurality of metal atoms and a plurality of hydrogen isotope atoms solid-dissolved among the plurality of metal atoms, and at least two of the plurality of hydrogen isotope atoms are condensed so that an inter-atomic nuclear distance between the two hydrogen isotope atoms is smaller than or equal to an internu-

clear spacing of a molecule consisting of the two hydrogen isotope atoms,

the heat generation method comprising:

applying energy to the hydrogen condensate;
and

generating heat by causing the at least two hydrogen isotope atoms to react with each other due to the energy.

2. A method according to claim 1, wherein the plurality of metal atoms are metal atoms of at least one species selected from the group consisting of palladium, titanium, zirconium, silver, iron, nickel, copper, and zinc.

3. A method of generating heat using a hydrogen condensate,

wherein the hydrogen condensate comprises a metal alloy composite containing a plurality of metal atoms and a plurality of hydrogen isotope atoms solid-dissolved among the plurality of metal atoms, and at least two of the plurality of hydrogen isotope atoms are condensed so that an inter-atomic nuclear distance between the two hydrogen isotope atoms is smaller than or equal to an internuclear spacing of a molecule consisting of the two hydrogen isotope atoms,

the heat generation method comprising:

applying energy to the hydrogen condensate;
and

generating heat by causing the at least two hydrogen isotope atoms to react with each other due to the energy.

4. A method according to claim 1 or 3, wherein the energy is generated based on at least one of ultrasonic wave, strong magnetic field, high pressure, laser, laser explosive flux-compression, high-density electron beam, high-density current, discharge, and chemical reaction.

5. A method according to claim 1 or 3, wherein in the step of generating heat, the at least two hydrogen isotope atoms are reacted with each other to generate a helium molecule in addition to the heat.

6. A hydrogen condensate, comprising:

a metal nano-ultrafine particle containing a plurality of metal atoms; and

a plurality of hydrogen isotope atoms solid-dissolved among the plurality of metal atoms,

wherein at least two of the plurality of hydrogen isotope atoms are condensed so that an inter-atomic nuclear distance between the two hydrogen

isotope atoms is smaller than or equal to an internuclear spacing of a molecule consisting of the two hydrogen isotope atoms.

7. A hydrogen condensate according to claim 6, wherein the plurality of metal atoms are metal atoms of at least one species selected from the group consisting of palladium, titanium, zirconium, silver, iron, nickel, copper, and zinc.

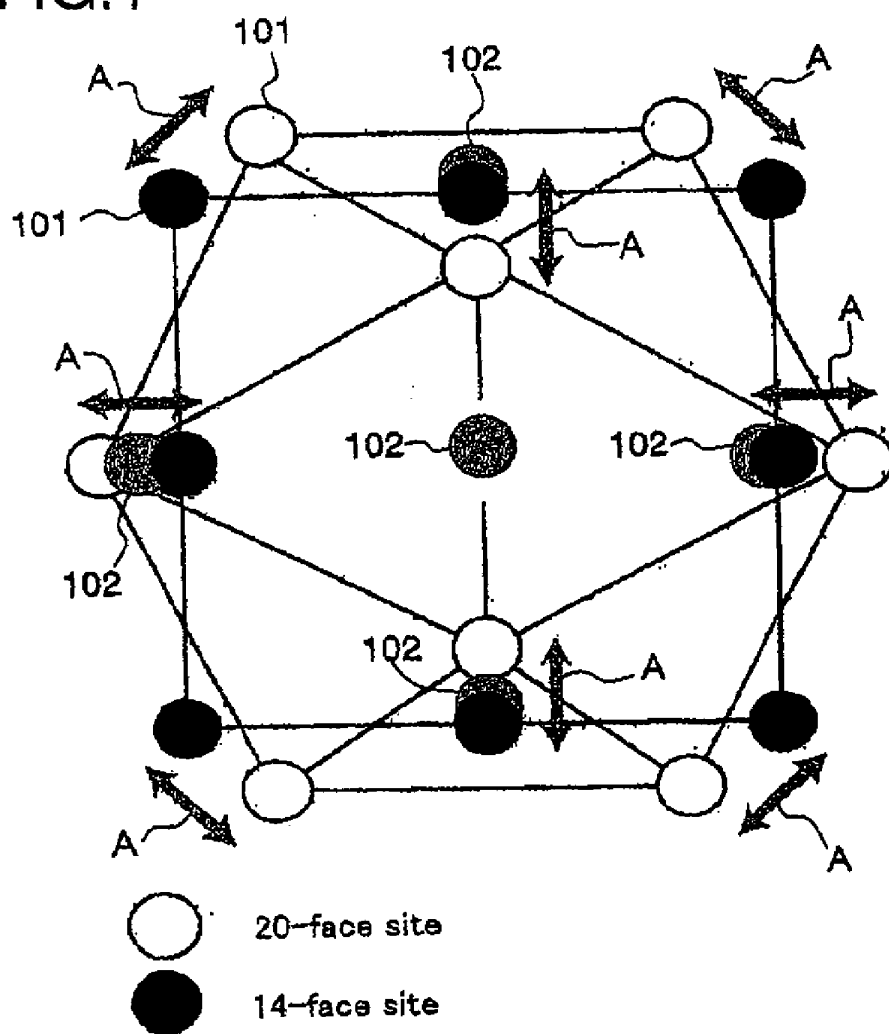
8. A hydrogen condensate, comprising:

a metal alloy composite containing a plurality of metal atoms; and

a plurality of hydrogen isotope atoms solid-dissolved among the plurality of metal atoms,

wherein at least two of the plurality of hydrogen isotope atoms are condensed so that an inter-atomic nuclear distance between the two hydrogen isotope atoms is smaller than or equal to an internuclear spacing of a molecule consisting of the two hydrogen isotope atoms.

FIG. 1



100

FIG.2

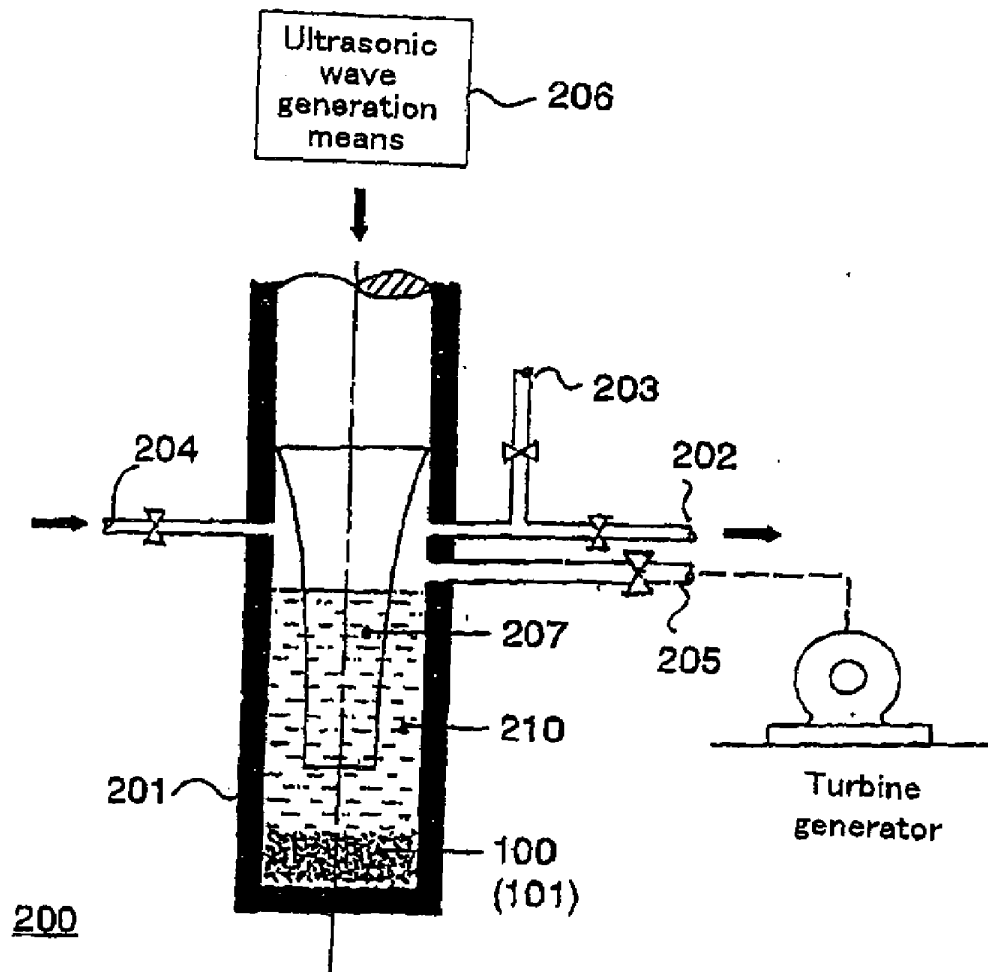


FIG.3

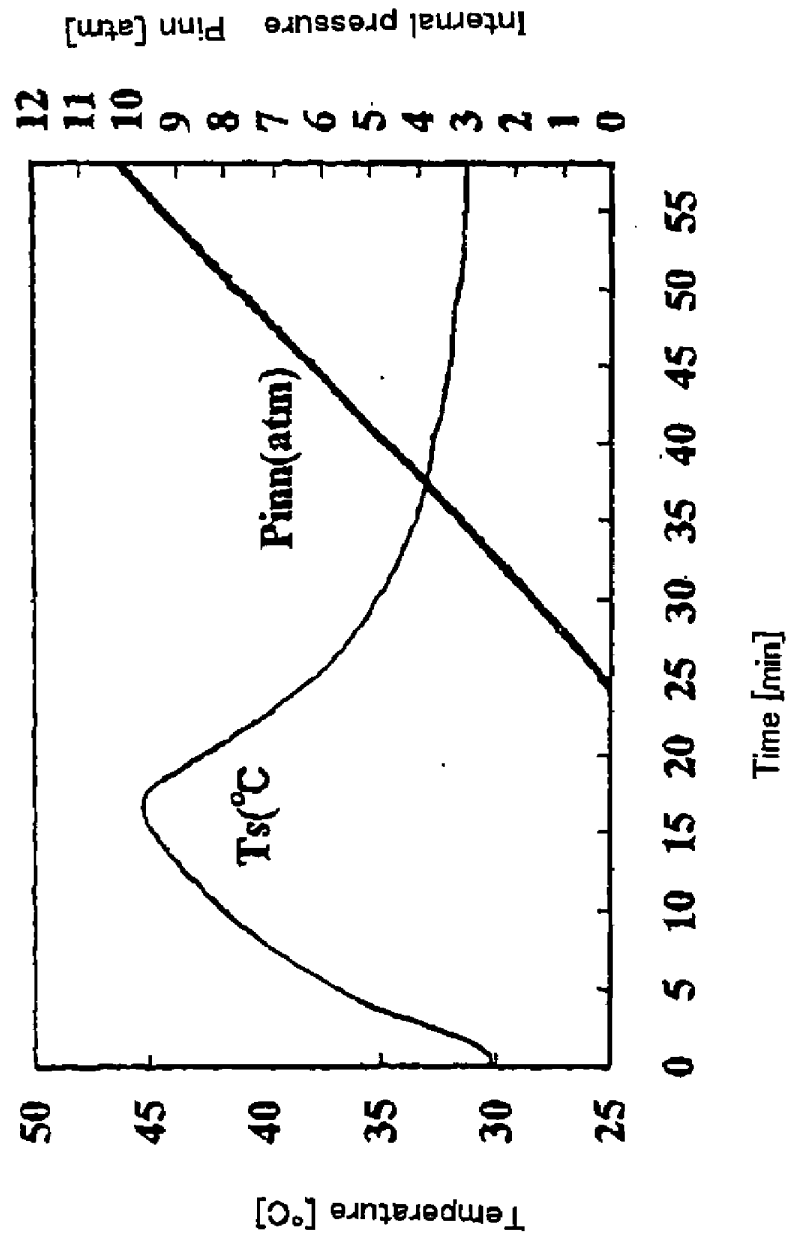


FIG.4

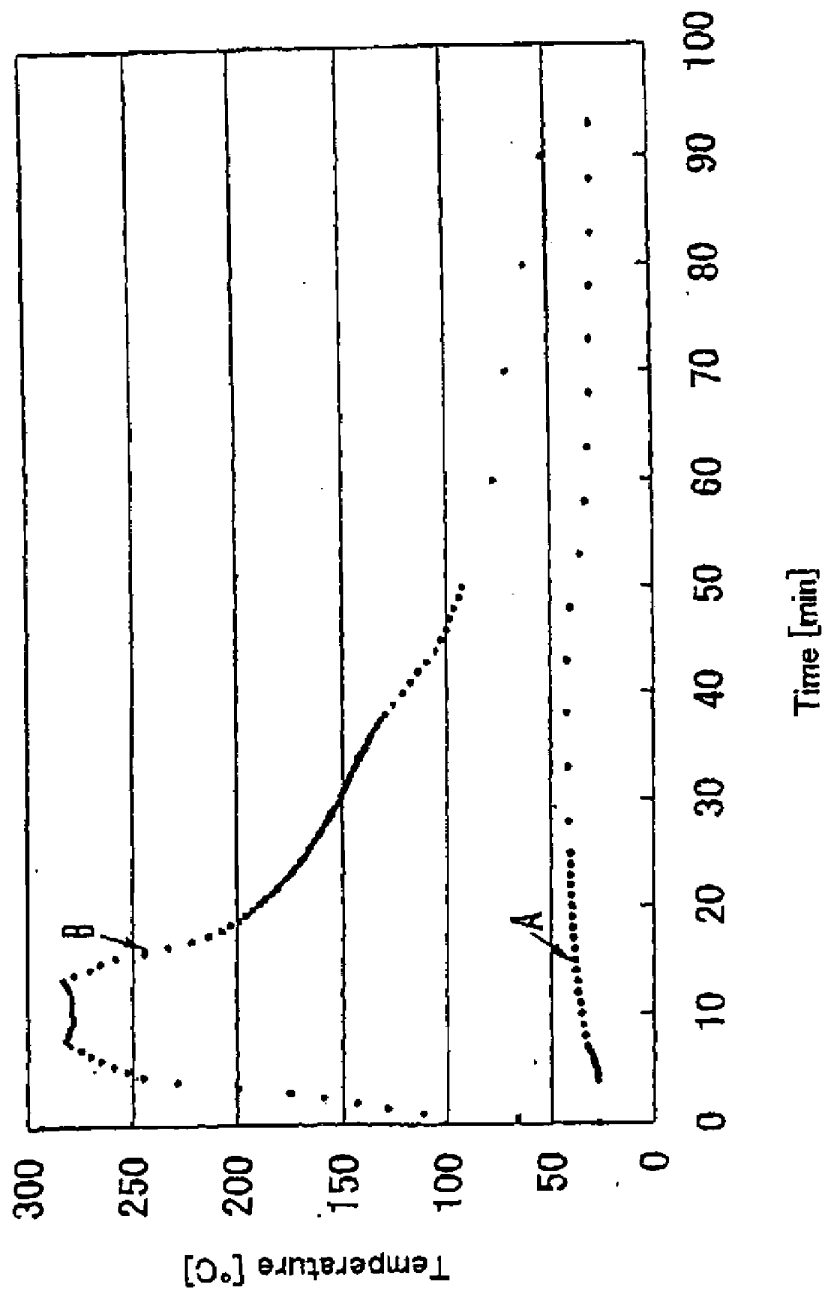


FIG.5

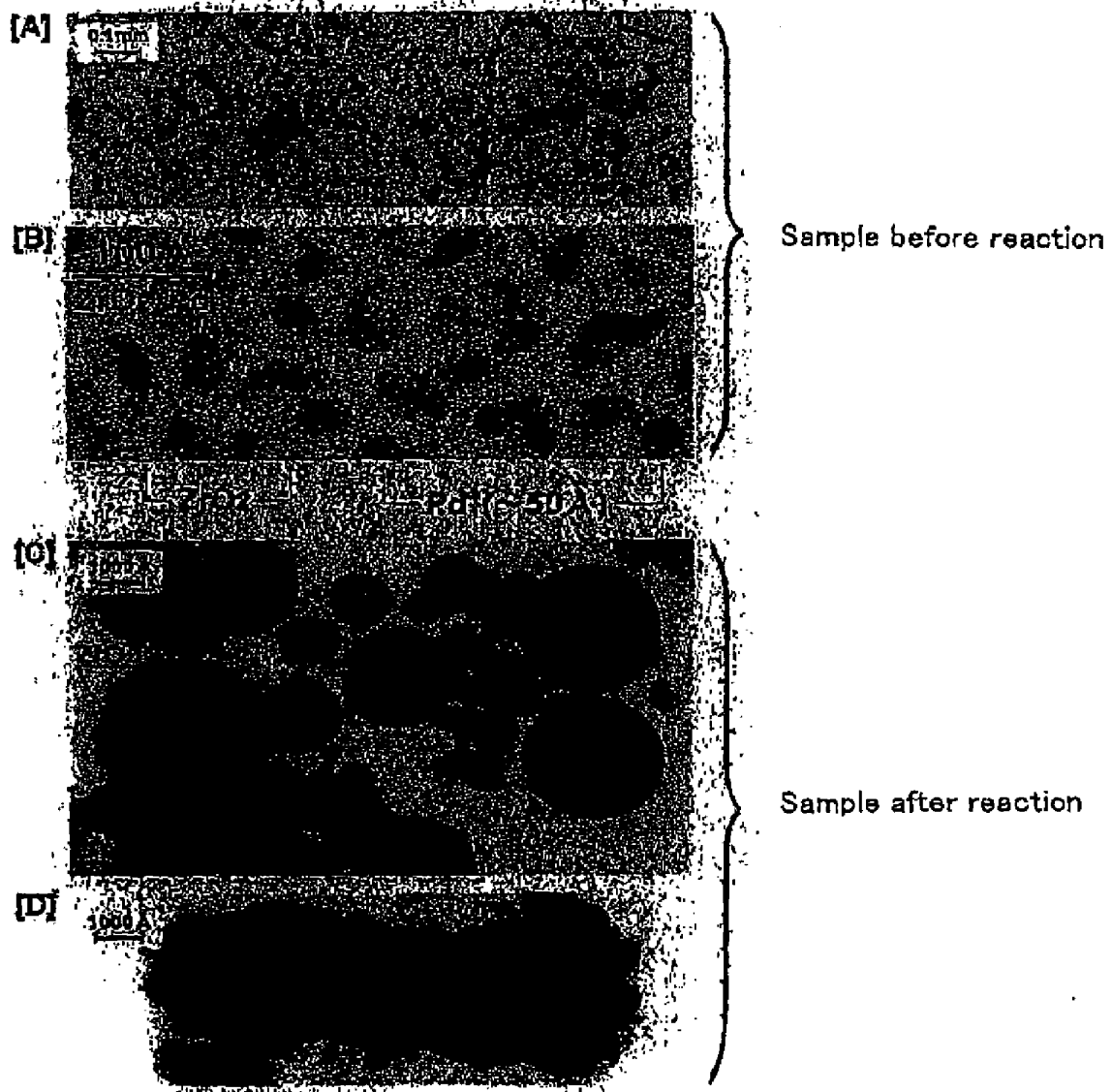


FIG.6A

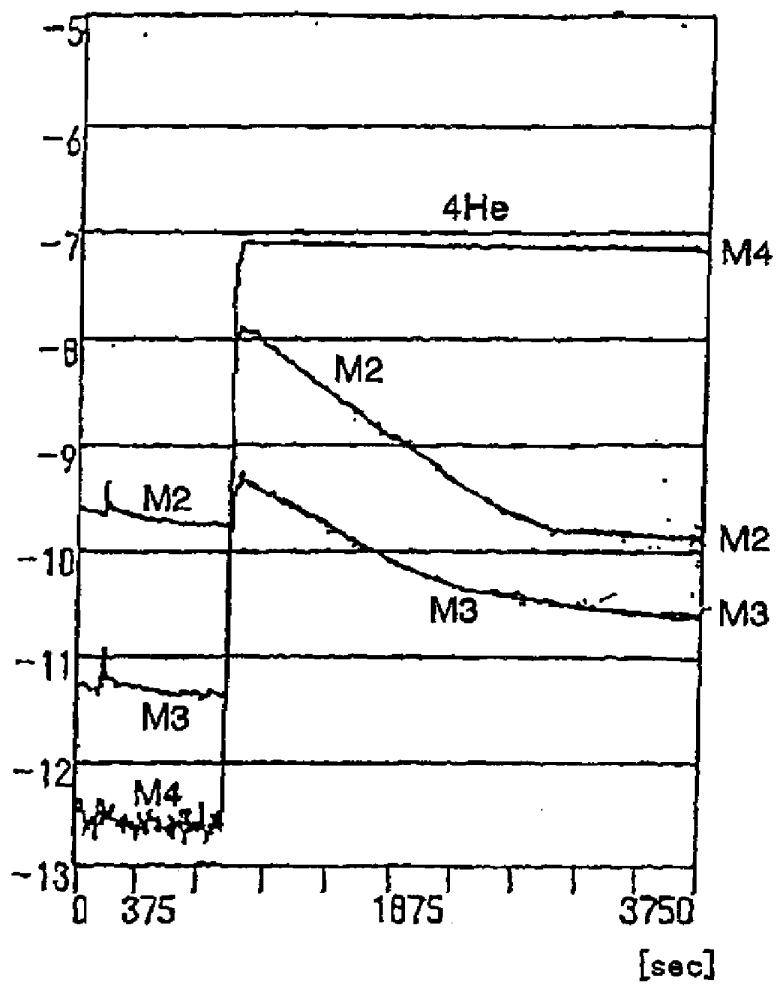


FIG. 6B

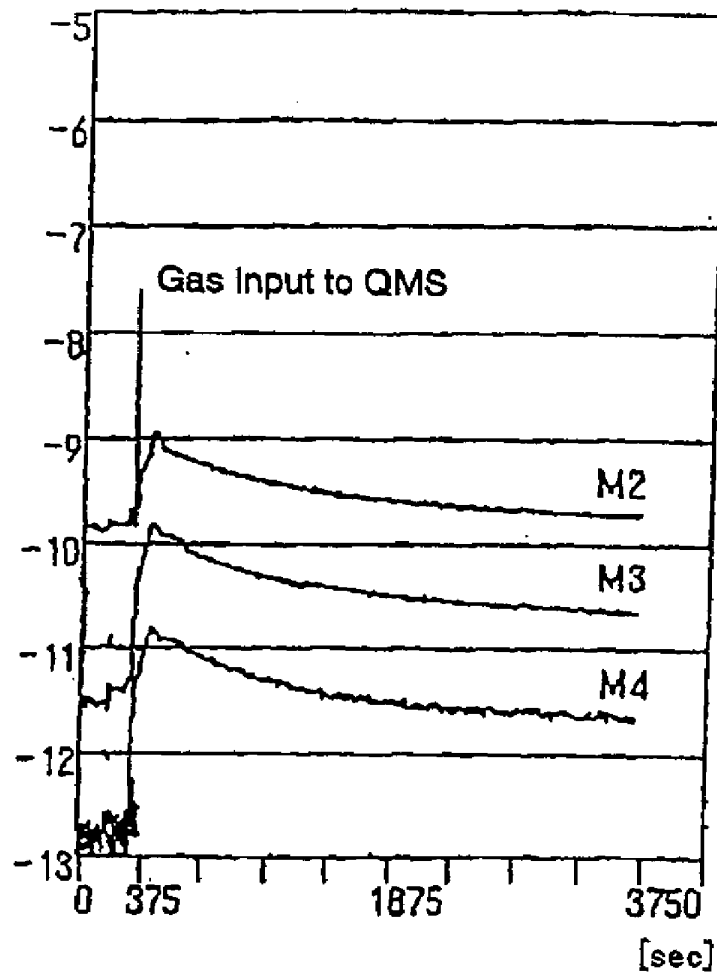


FIG.6C

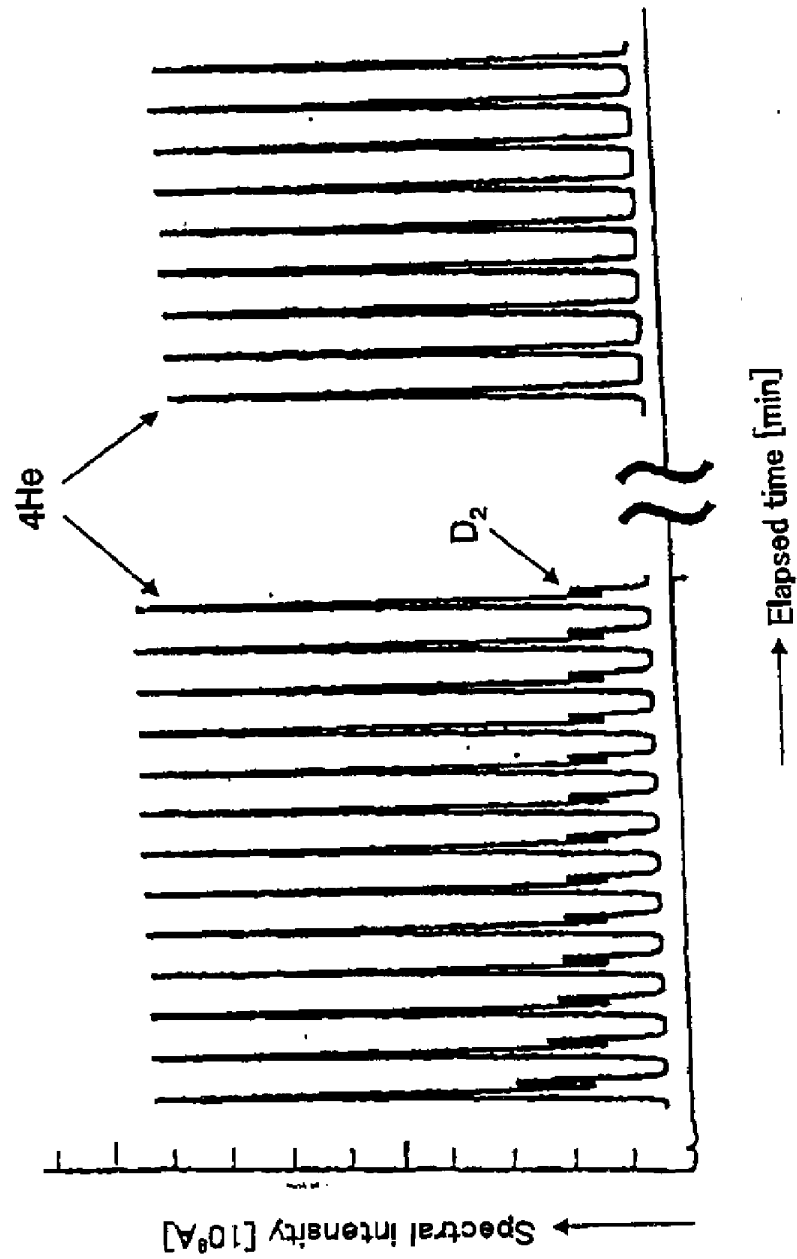
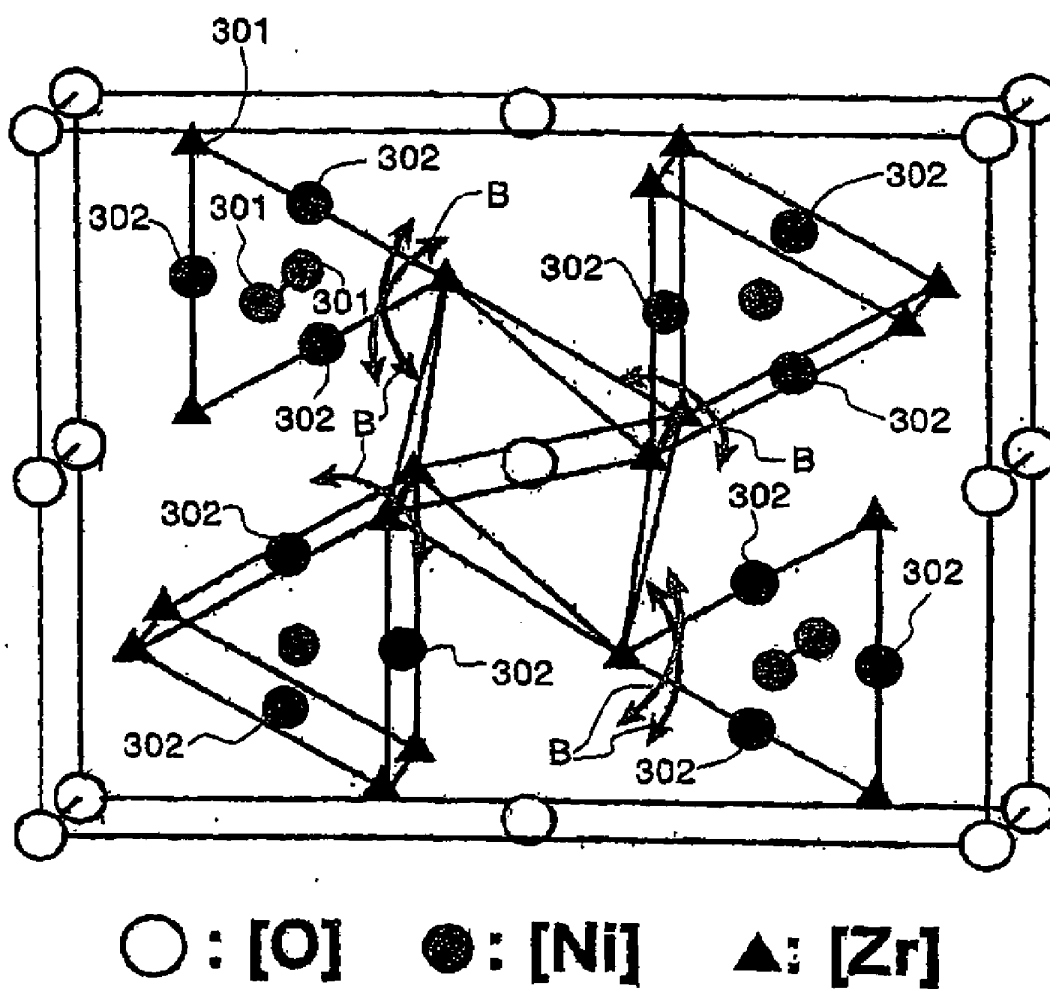


FIG.7



300

FIG.8

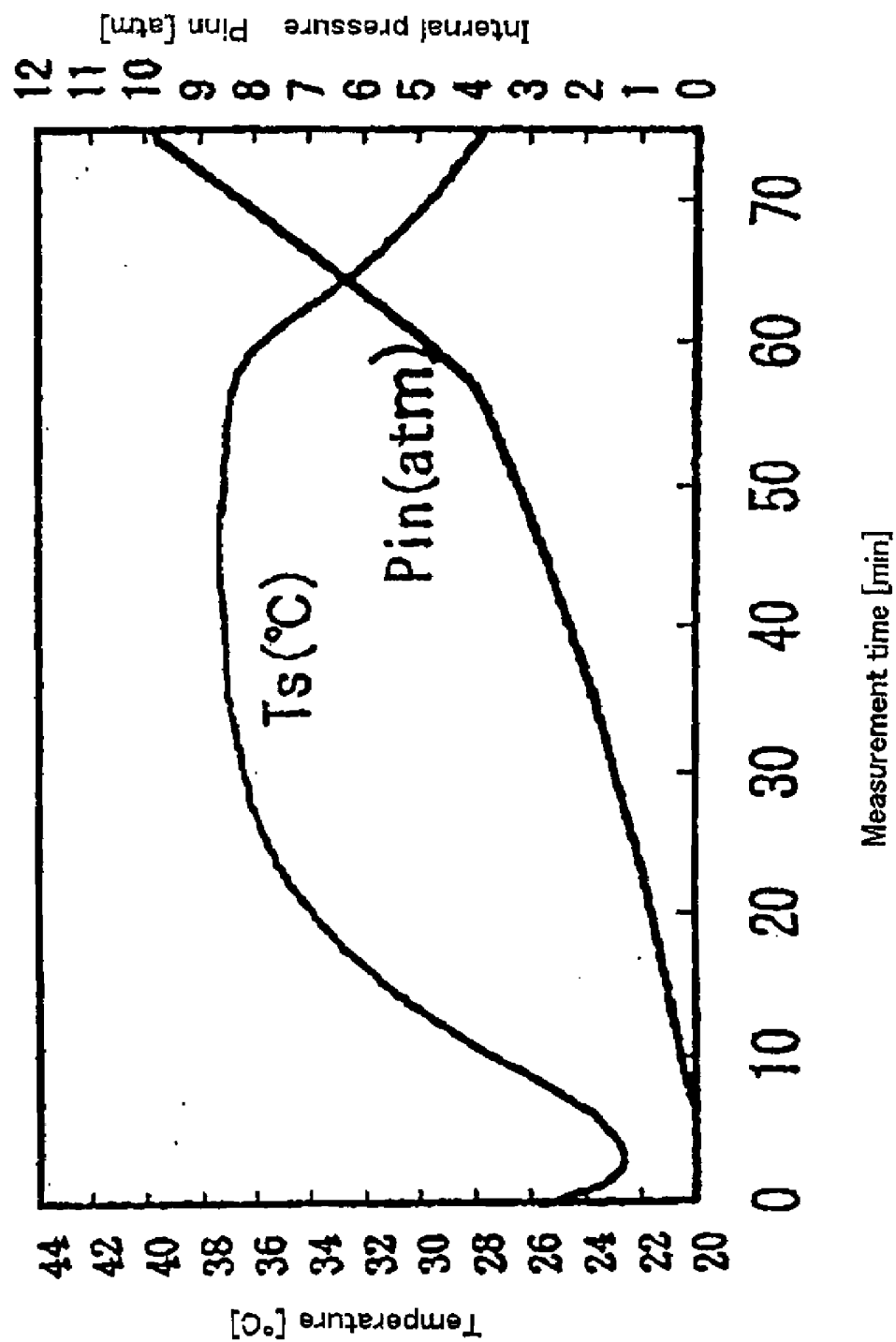


FIG.9

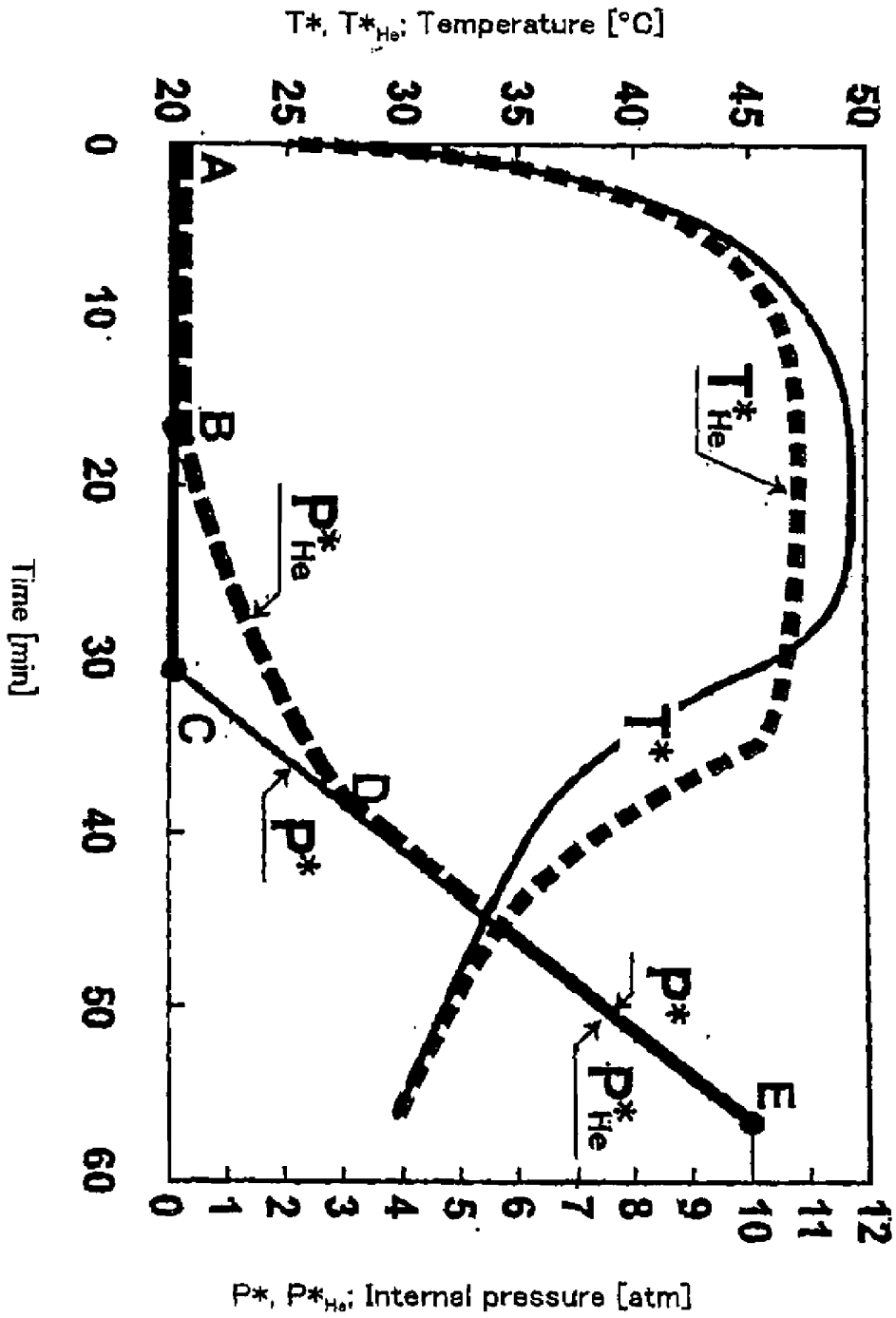


FIG.10

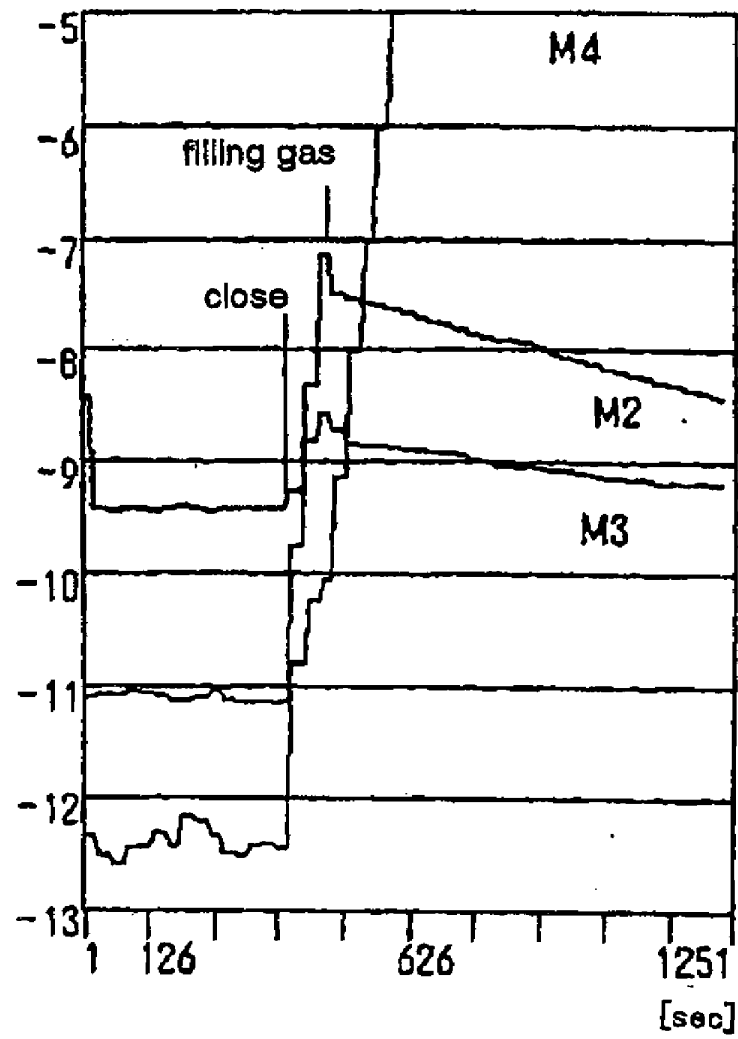
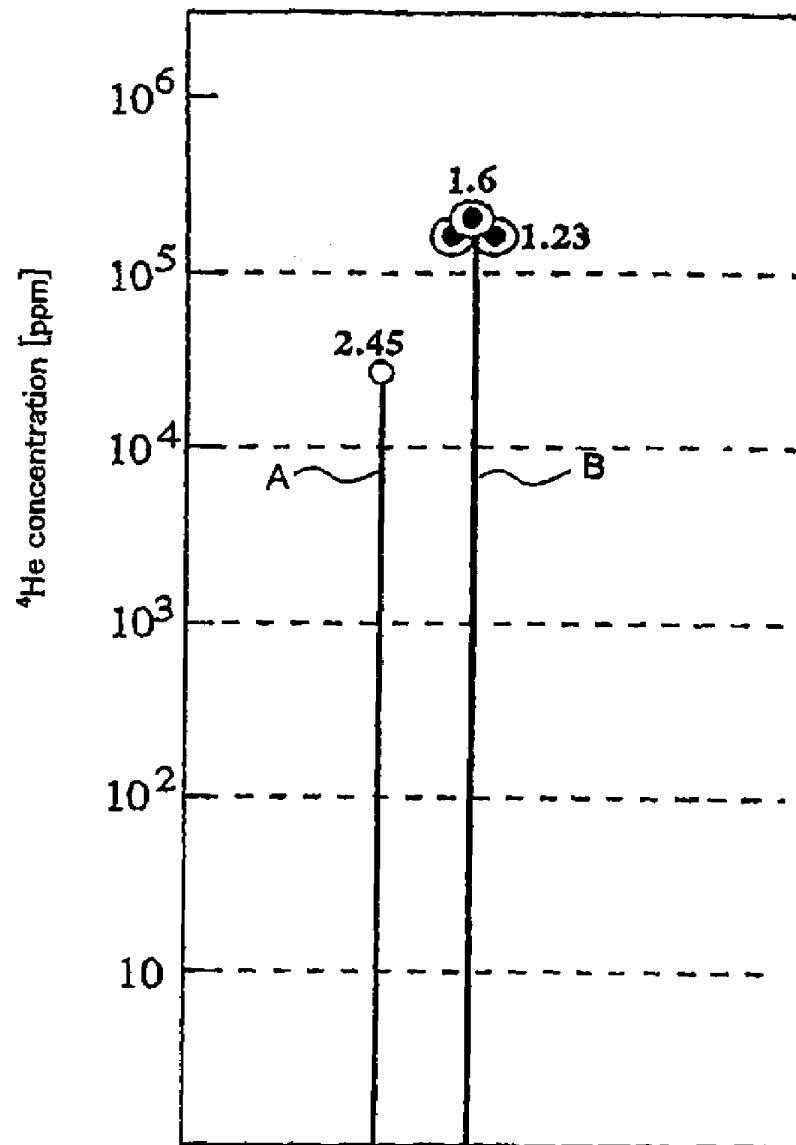


FIG.11



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP03/13095

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl⁷ G21B1/00, C01B3/00, B01J20/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl⁷ G21B1/00, C01B3/00, B01J20/06

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

| | | | |
|---------------------------|-----------|----------------------------|-----------|
| Jitsuyo Shinan Koho | 1926-1996 | Toroku Jitsuyo Shinan Koho | 1994-2003 |
| Kokai Jitsuyo Shinan Koho | 1971-2003 | Jitsuyo Shinan Toroku Koho | 1996-2003 |

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|-------------------------------------------------------------------------------------------------------------|-----------------------|
| X | JP 6-222173 A (Yoshiaki ARATA), 12 August, 1994 (12.08.94), The column of operation (Family: none) | 1-8 |
| X | JP 8-75882 A (Yoshiaki ARATA), 22 March, 1996 (22.03.96), The column of operation (Family: none) | 1-8 |

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

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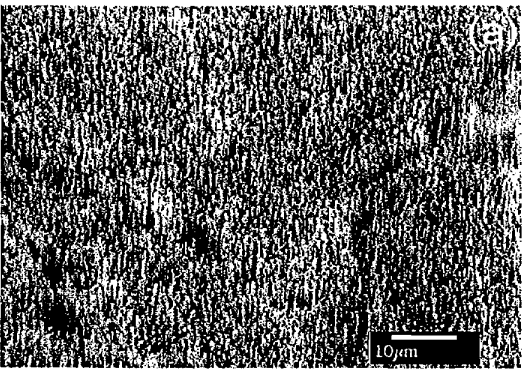
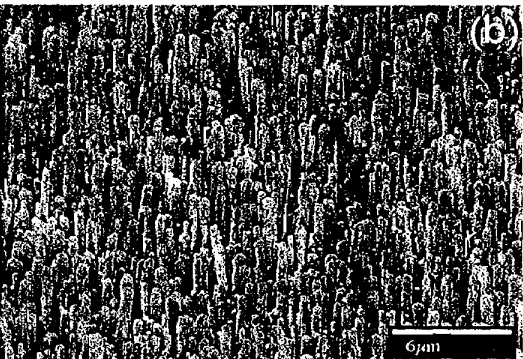
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| (54) Title: FREE-STANDING AND ALIGNED CARBON NANOTUBES AND SYNTHESIS THEREOF | | |
| (57) Abstract | | |
| <p>One or more highly-oriented, multi-walled carbon nanotubes are grown on an outer surface of a substrate initially disposed with a catalyst film or catalyst nano-dot by plasma enhanced hot filament chemical vapor deposition of a carbon source gas and a catalyst gas at temperatures between 300 °C and 3000 °C. The carbon nanotubes range from 4 to 500 nm in diameter and 0.1 to 50 μm in length depending on growth conditions. Carbon nanotube density can exceed to 10⁴ nanotubes/mm². Acetylene is used as the carbon source gas, and ammonia is used as the catalyst gas. Plasma intensity, carbon source gas to catalyst gas ratio and their flow rates, catalyst film thickness, and temperature of chemical vapor deposition affect the lengths, diameters, density, and uniformity of the carbon nanotubes. The carbon nanotubes of the present invention are useful in electrochemical applications as well as in electron emission, structural composite, material storage, and microelectrode applications.</p> <div style="display: flex; justify-content: space-around; align-items: flex-end;">   </div> | | |

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FREE-STANDING AND ALIGNED CARBON NANOTUBES AND SYNTHESIS THEREOF

This application claims the benefit of U.S. Provisional Patent Application Serial No. 60/089,965, filed June 19, 1998, and U.S. Provisional Patent Application Serial
5 No. 60/099,708, filed September 10, 1998.

This invention was made through the support of the U.S. Army Research Office (Grant No. DAAG55-97-1-0139). The Federal Government may retain certain rights in the invention.

FIELD OF THE INVENTION

10 The present invention relates to a product with a substrate having one or more carbon nanotubes, a method of producing that product, and devices utilizing the product.

BACKGROUND OF THE INVENTION

15 Since the first observation of carbon nanotubes, numerous papers have reported studies on the yield of well-graphitized nanotubes, their diameter and wall thickness (single or multiple), growth mechanisms, alignment, electron emission properties, nanodevices, theoretical predictions, and potential applications. Selective positioning and growth of carbon nanotubes is necessary for future integration with conventional microelectronics as well as the development of novel devices. However,
20 limited progress has been reported in the controlled placement of nanotubes. Alignment of the carbon nanotubes is particularly important to enable both fundamental studies and applications, such as cold-cathode flat panel displays, chargeable batteries, and vacuum microelectronics.

Specifically, vertical alignment has been an important goal due to its
25 technological importance for applications such as scanning probe microscopy and field emission flat panel displays. Attempts to manipulate nanotubes for these applications have been made by post-growth methods such as cutting a polymer resin-nanotube composite, or drawing a nanotube-ethanol suspension through a ceramic filter. Because these techniques are difficult and labor intensive, *in situ* aligning of nanotubes during

growth using techniques such as the nanopores of porous alumina membranes and laser etched nanotracts have been attempted.

There has been little success in obtaining alignment of carbon nanotubes on large areas until the report by Li et al., "Large-Scale Synthesis of Aligned Carbon Nanotubes," Science, 274:1701-1703 (1996) ("Li"). Li discusses the growth of aligned carbon nanotubes on mesoporous silica containing iron nanoparticles via thermal decomposition of acetylene gas in nitrogen gas at temperatures above 700°C. In this method, the substrate is prepared by a sol-gel process from tetraethoxysilane hydrolysis in iron nitrate aqueous solution. The gel is then calcined 10 hours at 450°C at 10^{-2} Torr. A silica network with relatively uniform pores is obtained with iron oxide nanoparticles embedded in the pores. The iron oxide nanoparticles are then reduced at 550°C in 180 Torr of flowing (9% H₂ / N₂ (110 cm³ / min) for 5 hours to obtain iron nanoparticles. Thereafter, nanotubes are grown in a gas environment of a mixture of 9% acetylene in nitrogen at 700°C. Aligned nanotube growth is along the axial direction of the pores. Only the nanotubes which grow out of the vertical pores are aligned. Nanotubes which grow from the iron particles on the surface and in the dispersed, inclined pores are random and non-oriented. In this method, nanotube alignment is limited to the constraint of the vertically aligned pores. Further, the density and diameter of aligned carbon nanotubes is respectively limited in direct proportion to the amount and size of the iron nanoparticles and the diameter of the pores.

As disclosed in Li, a temperature of at least 700°C is required to decompose acetylene and induce carbon nanotube growth. Unfortunately, this high temperature requirement limits substrate selection. For example, a glass substrate is unsuited for use in this method due to its low strain point temperature. A glass produced by Corning Incorporated (Corning, New York) has the highest known flat panel display glass deformation or strain point temperature of 666°C. Typically, a commercially available flat panel display glass has a strain point temperature between 500°C and 590°C. At 700°C, glass substrates deform and inhibit aligned carbon nanotube growth. Accordingly, any substrate suitable for use with this method must have a melting point or strain point temperature above 700°C.

Terrones et al., "Controlled Production of Aligned-Nanotube Bundles," Nature, 388: 52-55 (1997) ("Terrones") disclose a method for laser induced growth of

nanotube bundles aligned on a substrate under high temperature conditions. A thin film of cobalt is deposited on a silica plate by laser ablation and thereafter etched with a single laser pulse to create linear nanotracks. 2-amino-4,6-dichloro-s-triazine is then disposed onto the silica plate in the presence of argon gas within a two stage oven. The first oven is heated to 1,000°C and then allowed to cool to room temperature. The second oven is heated to and maintained at 950°C. Although carbon nanotubes grow along the edges of the eroded nanotracks, growth only occurs on the substrate bottom surface and in a non-vertical fashion. Carbon nanotubes do not grow on a similarly prepared substrate top surface which indicates nanotube growth according to this method is gravity dependent. Again, for the reasons discussed above, substrate selection for this method is limited to a substrate having either a strain point or melting point temperature above 1,000°C. Further, nanotube density is directly limited to the number of nanotracks etched into the substrate surface.

Thus, there remains a need for a method of forming aligned, vertically or otherwise, carbon nanotubes at temperatures below 700°C. Similarly, there remains a need for a substrate which has carbon nanotubes vertically aligned on the substrate surface. Further, there remains a need for a method of forming individual, free-standing carbon nanotubes, and a substrate with one or more individual, free-standing carbon nanotubes disposed on the substrate surface. The present invention is directed to overcoming these deficiencies in the art.

SUMMARY OF THE INVENTION

The present invention relates to a product which has a substrate and either (1) a plurality of substantially aligned carbon nanotubes of a density greater than 10^4 nanotubes per square millimeter of substrate, (2) a plurality of substantially aligned carbon nanotubes of a density no greater than 10^2 nanotubes per square millimeter of a substrate, (3) one or more carbon nanotubes, wherein the substrate has a strain point or melting point temperature between about 300°C and 700°C, (4) a plurality of substantially aligned carbon nanotubes originating and extending outwardly from the substrate outer surface, or (5) one or more free-standing carbon nanotubes originating and extending outwardly from the substrate outer surface.

Carbon nanotubes are synthesized by plasma-enhanced hot filament chemical vapor deposition of a carbon source gas in a reduced pressure environment in the presence of a catalyst gas at temperatures as low as between 300°C and 3000°C in a volume ratio range of carbon source gas to catalyst gas from 1:2 to 1:10. Growth of large arrays of well-aligned carbon nanotubes having a diameter between 4 to 500 nm occur on a substrate coated with a thin metal catalyst film. Free-standing carbon nanotubes are grown on metal catalyst nano-dots disposed on the substrate.

The present invention provides a method of forming aligned, vertically or otherwise, carbon nanotubes at temperatures below 700°C. Further, products made in accordance with this method provide a substrate which has carbon nanotubes vertically aligned on the substrate surface. Further, a product made in accordance with the method of the present invention includes a substrate having individual, free-standing carbon nanotubes. Still further, a product made in accordance with the method of the present invention includes a substrate having one or more individual, free-standing carbon nanotubes disposed on the substrate surface. Products of the present invention are useful in electrochemical applications as well as in electron emission, structural composite, material storage, and microelectrode applications.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1A-B are scanned images showing alignment of carbon nanotubes grown on a large-area of polycrystalline Ni substrates.

Figure 2 is a scanned image of a scanning electron microscope micrograph of showing carbon nanotubes grown at a higher plasma intensity under the conditions listed in Table 1(b).

Figure 3 is a scanned image showing carbon nanotubes with higher aspect ratios synthesized with a higher plasma intensity than that used for the carbon nanotubes shown in Figure 2.

Figure 4 is a scanned image showing a cluster of carbon nanotubes scraped off a Ni substrate directly onto a Cu TEM grid, with the insert showing a cross-section image from a portion of a single multi-walled carbon nanotube structure.

Figures 5A-B are scanned images showing carbon nanotubes aligned substantially perpendicular to a substrate over large areas growth conditions as listed in Table 2. Figure 5B is an enlarged view of Figure 5A along a peeled edge to show carbon nanotube diameters, length, straightness, and uniformity.

5 Figures 6A-C are scanned images showing scanning electron microscope surface morphology of the nickel catalyst layers. Figure 6A illustrates the effects of NH_3 plasma etching for 3 minutes. Figure 6B illustrates the effects of N_2 plasma etching for 3 minutes. Figure 6C shows an as-sputtered smooth catalyst surface.

10 Figures 7A-B are scanned images showing carbon nanotubes grown under the conditions listed in Table 2. Figure 7B is an enlarged view of Figure 7A to show carbon nanotube diameters and distributions.

15 Figure 8A is a scanned image showing thinner carbon nanotubes grown on thinner (15 nm) nickel-coated glass under the conditions listed in Table 2. Figure 8B is a scanned image showing carbon nanotube with approximately 20 nm diameters grown under the conditions listed in Table 2.

Figures 9A-B are scanned images showing the interior and wall structures of a typical thin carbon nanotubes, wherein Figure 9A is a cross-section view and Figure 9B is a plan view.

20 Figure 10 is a scanned image showing the large area growth of well-aligned carbon nanotubes on glass.

Figure 11 is a scanned image showing well-aligned carbon nanotubes on silicon.

Figure 12 is a scanned image showing very short carbon nanotubes grown on silicon for only 2 minutes.

25 Figure 13 is a scanned image showing open ended carbon nanotubes etched by HNO_3 for 1 minute.

Figure 14 is a scanned image showing carbon nanotubes subjected to Ar ion sputtering.

Figure 15 is a scanned image showing a side view of well-aligned carbon nanotubes grown at an angle with respect to the substrate.

5 Figure 16 is a scanned image showing a top view of the carbon nanotubes of Figure 15.

Figure 17A is a scanned image showing grown carbon nanotubes at the edge of a metal pad. Figure 17B is a scanned image showing a region similar to Figure 17A in which the carbon nanotubes are broken.

10 Figures 18A-F are a series of scanned images displaying various viewing angles of carbon nanotube obelisks grown from a patterned array of catalyst nano-dots. Figure 18A is a perspective view of a plurality of patterned arrays. Figure 18B is a top view of the patterned arrays of Figure 18A at a reduced magnification. Figure 18C is a perspective view of one patterned array. Figure 18D is a top view of one patterned array.
15 Figure 18E is a perspective view at an increased magnification of the patterned array of Figure 18C. Figure 18F is a perspective view of spaced-apart carbon nanotube obelisks.

Figure 19 is a scanned image showing an elevation view of a carbon nanotube obelisk.

20 Figure 20 is a partial, top view of a field emission display apparatus of the present invention.

Figure 21 is a perspective view of a probe for a scanning electron microscope of the present invention.

Figure 22 is a schematic illustrating an example of a scanning electron microscope of the present invention.

25 Figure 23 is a schematic drawing illustrating an example of the basic construction of a battery of the present invention.

Figure 24 is a schematic drawing illustrating a fuel cell of the present invention.

Figure 25 is a schematic drawing illustrating an electromagnetic interference shield disposed between an electromagnetic interference source and an electronic component.

Figure 26 is a schematic drawing illustrating a microelectrode of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to a product which includes a substrate and one or more hollow core carbon nanotubes originating from a surface of the substrate. When the product has more than one carbon nanotube, the carbon nanotubes are well-aligned and may lie on or extend either perpendicularly or non-perpendicularly from the substrate surface. Embodiments of the product of the present invention include the substrate and either (1) a plurality of substantially aligned carbon nanotubes of a density greater than 10^4 nanotubes per square millimeter of substrate, (2) a plurality of substantially aligned carbon nanotubes of a density no greater than 10^2 nanotubes per square millimeter of a substrate, (3) one or more carbon nanotubes, wherein the substrate has a strain point or melting point temperature between about 300°C and 700°C , (4) a plurality of substantially aligned carbon nanotubes originating and extending outwardly from the substrate outer surface, or (5) one or more free-standing carbon nanotubes originating and extending outwardly from the substrate outer surface.

As shown in Figures 1-19, carbon nanotubes of the present invention are substantially concentric tubules. The nanotubes have diameters ranging from 4 to 500 nm and lengths up to 50 μm . Preferably, carbon nanotubes which are longer than 20 μm have a diameter of at least 50 nm to maintain alignment. Depending upon growth conditions, the carbon nanotubes can be either free-standing nanotube obelisks which have a sharp, tapered carbon tip or a large array of well-aligned nanotubes which have a cap distally located from the substrate. The large arrays of carbon nanotubes have densities of 10^6 to 10^8 nanotubes per square millimeter of substrate. The cap comprises a catalyst metal or metal alloy material of iron, cobalt, nickel, or an alloy of iron, cobalt, or nickel. The

catalyst material and its role is discussed further below. In an embodiment of the present invention, the tips and caps are removed to reveal open-ended carbon nanotubes.

It is contemplated that a wide variety of electrically or non-electrically conductive substrates can be utilized with the present invention. For example, suitable substrates include glass, silica, quartz, silicon, platinum, iron, cobalt, nickel, an alloy of iron, cobalt, or nickel, a ceramic, or a combination thereof. Particularly useful substrates are glass panels and silicon wafers. It is important to recognize that the most important property of the substrate is that the substrate strain point and/or melting point temperatures are above the temperature of carbon nanotube growth. With the present invention, the substrate must have strain point and/or melting point temperatures of at least about 300°C. As disclosed in Li, substrates utilized in the prior art must have strain point and/or melting point temperatures in excess of 700°C. Accordingly, a product of the present invention and the substrate therein have a strain point or melting point temperature between 300°C and 700°C. Such substrates include flat panel display glass substrates, which have strain point and/or melting point temperatures of 666°C and below, may be utilized. Certain ceramics, such as LaAlO₃, Al₂O₃, and ZrO₂, YSZ, and SrTiO₃ have melting point temperatures of about 3000°C and are useful as substrates utilized in high temperature environments.

In the present invention, carbon nanotubes are uniquely grown on a surface of a substrate by providing the substrate in a reduced pressure environment containing a carbon source gas and a catalyst gas and exposing the substrate to a plasma under conditions effective to cause formation and growth of one or more carbon nanotubes on the substrate. This is defined as plasma-enhanced hot filament chemical vapor deposition (PE-HF-CVD). Accordingly, the present invention is also directed to products which have carbon nanotubes originating and extending outwardly from an outer surface of the substrate.

Prior to growing the carbon nanotubes by PE-HF-CVD, the substrates are placed into a deposition chamber at a reduced pressure ($< 6 \times 10^{-6}$ Torr) and coated with the catalyst metal or metal alloys discussed above. Either a metal catalyst film of at least about 15 nm thick or one or more metal catalyst nano-dots of about 150Å thick is deposited onto the substrate. The catalyst film is deposited by radio frequency magnetron sputtering. The catalyst nano-dots are deposited by electron beam evaporation, thermal evaporation, or magnetron sputtering. Surprisingly, the resultingly grown carbon

nanotube diameters are directly related to the thickness of the catalyst film. By varying the thickness of the catalyst film, the diameter of the carbon nanotubes can be controlled. Although nano-dot thickness can have a like effect on resulting nanotube diameter, the thickness is less controlling as the film.

5 To produce the products of the present invention, the coated substrates are placed into a reduced pressure CVD chamber containing a carbon source gas and a catalyst gas and are then exposed to a plasma under conditions effective to cause formation and growth of one or more carbon nanotubes on the substrate surface. Generally, the CVD chamber has a pressure between about 0.1 to about 100 Torr, preferably about 1 to about 20 Torr. Because carbon nanotube growth is induced by plasma enhanced chemical vapor deposition of the carbon source gas, the heated environment of the CVD chamber can be maintained at a temperature between about 300°C and about 3000°C. As a result of the low temperature requirement, various substrates having relatively low strain point or melting point temperatures as low as about 10 300°C may be utilized in the present invention. As indicated above, carbon nanotube growth may occur at very high temperatures and is only constrained by the melting point temperature of the selected substrate. The upper temperature limit of carbon nanotube growth is estimated to be about 3000°C, which corresponds to the highest known ceramic substrate melting point temperature, as discussed above. The growth time depends on the 15 requirement of nanotube length. Normally, it is between 1 – 10 minutes, which yields a length of 0.1 – 20 µm. Growth durations can extend up to 5 hours depending on the desired carbon nanotube lengths.

 The carbon source and catalyst gases flow through the CVD chamber with a volume ratio of carbon source gas to catalyst gas ranging from 1: 2 to 1:10 at a 25 maintained pressure between about 0.1 to about 100 Torr at a temperature between about 300°C to 3000°C. The carbon source gas may be selected from saturated or unsaturated linear, branched, or cyclic carbon and hydrogen compounds having up to six carbon atoms which are gases at the deposition pressure. For example, very pure (99.99% purity) acetylene, ethylene, and benzene, preferably acetylene, may be utilized as the 30 carbon source gas of the present invention. The catalyst gas is ammonia (99.99% purity) at CVD temperatures below 700°C. At CVD temperatures above 700°C, the catalyst gas may be ammonia, nitrogen (99.99% purity), or a combination thereof. Ammonia is the preferred catalyst gas of the present invention. Preferably, the carbon source and catalyst

gases are introduced into the CVD chamber simultaneously or the catalyst gas is introduced prior to the carbon source gas.

Carbon nanotubes are synthesized with the diameter, length, site density, and growing angle controlled. Plasma intensity may be varied to determine the nanotube aspect ratios for diameter and length, and range of both site and height distributions. Vertical or non-vertical growth of the carbon nanotubes is independent of the substrate surface topography and can be controlled by the angle placement of the substrate in the CVD chamber with respect to the orientation of the electric field of the plasma generator.

These lower temperature growth conditions are suitable for electron emission applications, such as cold-cathode flat panel displays which require the carbon nanotube emitters to be grown substantially perpendicular to a glass substrate surface. However, carbon nanotubes grown at the lower temperatures have more wall defects or discontinuities. These discontinuities provide a diffusion path to the nanotube core. Should there be a desire to manufacture carbon nanotubes with limited defects, higher growth temperatures may be utilized.

The growth mechanism of aligned carbon nanotubes is ascribed in the literature to be a constraint of either the pores in mesoporous silica or the laser etched tracks in silica. In the present invention, the alignment of the carbon nanotubes cannot be due to pores or etched tracks since there are no pores or etched tracks in the glass substrates, as shown in Figures 5A-B, 10, 15, 17A-B, and 18C, E, and F. Rather, alignment is due to a nanotube nucleation process catalyzed by the catalyst gas (e.g., ammonia) and the catalyst layer or nano-dot (e.g., nickel). In the presence of the catalyst gas, each metal catalyst cap efficiently catalyzes the continuous synthesis of carbon nanotubes. With the growth of the carbon nanotubes, the cap is maintained at the distal end of each carbon nanotube. The alignment and thickness of the carbon nanotubes may be determined by the orientation and size respectively of the initial catalytic centers. If desired, the catalyst metal caps can be removed by subjecting the carbon nanotubes to either HNO₃ solution etching or Ar ion sputtering to open the distal ends.

In some applications, a single carbon nanotube or patterns with controlled site density is desired, which can be accomplished by selective deposition of the catalyst nano-dots. In the present invention, the carbon nanotubes grown from the metal catalyst nano-dots are obelisks which have tapered, sharp carbon tips and have rounded base diameters approximately the same as the nano-dots. The nanotube height depends on the

growth time and nano-dot thickness. The tips can be removed as well to provide an open ended nanotube by placing the nanotubes in a reaction chamber and exposing the nanotubes to oxygen and heat at about 400°C for about 0.5 hour.

5 A filling can be placed within the carbon nanotubes through the open ends or through the structural discontinuations. For example, fillings such as hydrogen, lithium ions, bismuth, lead telluride, bismuth tritelluride, or a pharmacological agent, to name only a few, may be inserted into the nanotube core by electrochemical or physical methods. If desired, the open ends of the carbon nanotubes can be enclosed or sealed by magnetron sputtering or electrochemical deposition of an enclosing material, such as a
10 metal.

Now, referring to Figure 20, a conventional flat panel display or field emission display 100 has a baseplate 102, a spaced-apart phosphor coated faceplate 104, and an electron emitter array 106 positioned on the baseplate 102 for emitting electrons to impinge upon and thereby illuminate the phosphor coating. The baseplate 102, the
15 faceplate 104 and the emitter array 106 are disposed in a vacuum environment. The emitter 106, which is operably connected to an electron generating source, has a sharp tip 108, known as a Spindt tip, to emit electrons. However, these emitters 106 have certain drawbacks because they have a relatively short wear life, have a low emission density due to the limits of existing lithography technology, and are relatively expensive. Products of
20 the present invention comprising large arrays of well-aligned carbon nanotubes as shown in, for example, Figures 1, 2, 5, 7, 10, 11, and 18B, can be used to replace the base plate/emitter array combination 102 and 106. Since the carbon nanotubes can be produced highly aligned and perpendicular to the substrate, field emission displays can be fabricated utilizing such arrays as emitters. Further, as discussed in Schmid et al.,
25 "Carbon Nanotubes Are Coherent Electron Sources," Appl. Phys. Lett., 70(20):2679-2680 (1997)("Schmid"), Collins et al., "A Simple And Robust Electron Beam Source From Carbon Nanotubes," Appl. Phys. Lett., 69(13):1969-1971 (1996), and Rinzler et al., "Unraveling Nanotubes: Field Emission From an Atomic Wire," Science, 269: 1550-1553 (1995) ("Rinzler"), all of which incorporated herein by reference, carbon nanotubes emit
30 electrons in the same manner as the Spindt tips upon operable connection to an electron generating source. Not only can the carbon nanotubes increase emitter wear life, contrast and brightness are improved as well due to the large nanotube density.

Referring to Figures 19, 21, and 22, and generally to Figures 1-18, the products of the present invention can be utilized as a probe for a scanning electron microscope, as indicated in Rinzler. A scanning electron microscope 200 of the present invention comprises a vacuum chamber 202 capable of receiving a specimen 204, an electron source 206 for producing electrons, a probe 208 which is operably positioned within the vacuum chamber 202 for emitting and directing the electrons toward and scanning the specimen 204, a detector 210 operably positioned within the vacuum chamber 202 for collecting radiation issuing from the specimen 204 as a result of scanning by the probe 208 to produce an output signal, and a display screen 212 operably connected to the detector 210 to receive the output signal and resulting display an image of the area of the specimen 204 scanned by the probe 208. Referring to Figures 1-5B, 7-19 and 21, the probe 208 is a product of the present invention having a substrate and either (1) a plurality of substantially aligned carbon nanotubes of a density greater than 10^4 nanotubes per square millimeter of substrate; (2) a plurality of substantially aligned carbon nanotubes of a density no greater than 10^2 nanotubes per square millimeter of a substrate; (3) one or more carbon nanotubes, wherein the substrate has a strain point or melting point temperature between about 300°C and 700°C; (4) a plurality of substantially aligned carbon nanotubes originating and extending outwardly from an outer surface of the substrate; or (5) one or more free-standing carbon nanotubes originating and extending outwardly from an outer surface of the substrate. Preferably, the probe 208 is a product of the present invention comprising a substrate 214 having an outer surface 216 and one free-standing carbon nanotube 218 originating and extending from the outer surface 216 of the substrate 214.

Selective positioning and growth of a single, free-standing carbon nanotube from a single, catalyst nano-dot in accordance with the method of the present invention as previously described can produce the probe 208. Referring to Figure 21, and generally to Figure 19, a single, free-standing carbon nanotube 218 originating and extending from an outer surface 216 of a substrate 214 is operably connected to the electron source 206. The substrate 214 is selected from an electrically conductive material, which is connectable to the electron source.

In operation, the specimen 204 is positioned within the vacuum chamber 202, and the chamber 202 is evacuated. The microscope 200 scans the specimen 204 with a fine probe of electrons emitting from the probe 208. The electrons are produced

from the electron source 206, which can be a field-emission electron source (not shown) and suitable accelerating electrodes (not shown), such as an electron gun (not shown). Electrons that are transmitted through the specimen 204 are collected by the detector 210 to provide the output signal. For example, the detector 210 can comprise a phosphor
5 screen (not shown) with a photomultiplier (not shown) for detecting light from the screen. This output signal is used to modulate the beam of the display screen 212, such as a cathode ray tube, which is scanned in synchronism with the probe 208, so as to cause the display screen 212 to display a pattern which depends on the structure of the scanned portion of the specimen 204. Alternatively, instead of collecting transmitted electrons,
10 secondary radiation (e.g., electrons or x-rays), emitted from the specimen 204 as a result of bombardment by the electrons of the probe 208, may be detected to provide the output signal.

In such a microscope, the electron fine probe or carbon nanotube 218 must be very fine, such as to illuminate only a small region of the specimen 204, in order to
15 enable small features of the specimen 204 to be examined. Production of a fine probe of electrons requires an electron source 206 having a very small electron-emitting area such as, for example, a field-emission electron source. Magnets 220 can be operably disposed in the vacuum chamber 202 to focus or alter the emitted electron probe. Carbon nanotubes produced in accordance with the present invention are such electron emitters.

20 The products of the present invention can also be utilized to form alkali metal ion batteries, such as, lithium batteries. As shown in Figure 23, the battery 300 comprises an anode 302, a cathode 304, an insulator 306 disposed between the anode 302 and the cathode 304, and an electrolyte 308. At least one of the anode 302 and the cathode 304, preferably both, comprise a product of the present invention having a
25 substrate and either (1) a plurality of substantially aligned carbon nanotubes of a density greater than 10^4 nanotubes per square millimeter of substrate; (2) a plurality of substantially aligned carbon nanotubes of a density no greater than 10^2 nanotubes per square millimeter of a substrate; (3) one or more carbon nanotubes, wherein the substrate has a strain point or melting point temperature between about 300°C and 700°C; (4) a
30 plurality of substantially aligned carbon nanotubes originating and extending outwardly from an outer surface of the substrate; or (5) one or more free-standing carbon nanotubes originating and extending outwardly from an outer surface of the substrate. Preferably,

the product has a plurality of substantially aligned carbon nanotubes of a density greater than 10^4 nanotubes per square millimeter of substrate.

Here, the substrate comprises an electrically conductive material, and the carbon nanotubes have at least one diffusion path to the hollow core of the nanotubes. As reported in Gao et al, "Electrochemical Intercalation of Single-walled Carbon Nanotubes with Lithium," Chem. Phys. Lett., (in press) ("Gao") alkali metals can be electrochemically intercalated into the hollow cores of carbon nanotubes. Gao also reports that lithium can be reversibly intercalated from the nanotubes in the range of 100-400 mAh/g. In the present invention, lithium ions may be intercalated into the carbon nanotubes of the anode 302 by charging the battery 300.

Although not required, the carbon nanotubes of the product may have open ends to provide the metal diffusion path, as shown in Figure 13. Preferably, the carbon nanotubes have high structural defect or discontinuation densities in the walls. As previously discussed, carbon nanotubes grown at low growth temperatures (e.g., 300°C to 400°C) by PE-HF-CVD have such structural discontinuations. These structural discontinuations provide high active surface areas and numerous diffusion paths to the nanotube core for metal diffusion. It is not necessary for the carbon nanotubes having discontinuations to be open-ended, since most metal diffusion occurs through the discontinuations.

In the present invention, the cathode 304 functions to assist conduction for collecting current, and the anode 302 functions as the host material for the lithium ions. Since the anode 302 and/or the cathode 304 comprises well-aligned carbon nanotubes, the electrolyte 308 easily permeates the nanotubes, which act as electrodes. As a result, impedance of the battery 300 is decreased, the charge-discharge efficiency is improved over conventional batteries, and secondary reactions during charge and discharge are prevented. Thus, the battery 300 of the present invention has a high capacity and a long life cycle.

When the cathode 304 comprises the product of the present invention having intercalated lithium ions, a higher collecting ability can be attained. As a result, the utilization of the cathode 304 can be increased to produce a high-capacity lithium battery 300.

Products of the present invention having carbon nanotubes substantially aligned and oriented substantially perpendicular with respect to the substrate are

preferred. By utilizing such products, the electrolyte 308 can permeate the nanotubes much easier. This results in the battery 300 being capable of rapid charge and discharge. In the anode 302, lithium can be deposited on the carbon nanotubes surfaces and intercalated into the nanotubes, thereby preventing the growth of dendritic lithium metal deposition and resulting in the battery 300 having a higher capacity. Also, when the products of the present invention are used as an anode 302 for intercalating and deintercalating lithium ions, a high-capacity anode 302 is formed.

Again referring to Figure 23, the anode 302 and the cathode 304 are disposed in the electrolyte 308 held in a housing 310 opposite to each other through the insulator 306. The insulator 306 is provided for preventing internal shorts due to contact between the anode 302 and the cathode 304. The anode 302 and the cathode 304 respectively can comprise the products shown in Figures 1-19. An anode terminal 312 and a cathode terminal 314 are electrically connected to the respective product substrates comprising the anode 302 and the cathode 304. The anode terminal 312 and the cathode terminal 314 may be utilized for at least a portion of the housing 310. When a lithium battery 300 of the present invention is assembled, the anode 302 and cathode 304 must be sufficiently dehydrated and dried. For example, dehydration can be performed by heating under reduced pressure.

The carbon nanotubes serve as the collecting electrodes of the anode 302 and the cathode 304. The nanotubes function to efficiently supply a current to be consumed by electrode reaction during charge and discharge or to collect the current generated by the electrode reaction.

The insulator 306 functions to prevent internal shorts between the anode 302 and the cathode 304, and can function to hold the electrolyte 308. The insulator 306 must have pores which permit movement of lithium ions, and must be insoluble and stable in the electrolyte 306. Thus, examples of materials which may be used for the insulator 306 include glass, polyolefins, such as polypropylene and polyethylene, fluororesins, and materials having a micropore and nonwoven fabric structure. A metal oxide film having micropores and a resin film compounded with a metal oxide can also be used.

An electrolyte solution is prepared by dissolving the electrolyte 308 in a solvent. Examples of electrolytes 308 include acids, such as H_2SO_4 , HCl , and HNO_3 , salts comprising lithium ions and Lewis acid ions (BF_4^- , PF_6^- , ClO_4^- , CF_3SO_3^- , and BPh_4^-).

and salt mixtures thereof. Salts comprising cations such as sodium ion, calcium ion, and tetraalkylammonium ion, and the Lewis acid ions can also be used. These salts can be sufficiently dehydrated and deoxidized by heating under reduced pressure.

Examples of solvents which are useful for the electrolyte 308 include
5 acetonitrile, benzonitrile, propylenecarbonate, ethylenecarbonate, dimethylcarbonate, diethylcarbonate, dimethylformamide, tetrahydrofuran, nitrobenzene, dichloroethane, diethoxyethane, 1,2-dimethoxyethane, chlorobenzene, gamma -butyrolactone, dioxolan, sulfolan, nitromethane, 2-methyltetrahydrofuran, 3-propylsydnone, sulfurdioxide, phosphorylchloride, thionylchloride, sulfurylchloride, and solvent mixtures thereof.
10 These solvents can be dehydrated by activated alumina, molecular sieves, phosphorus pentaoxide, or calcium chloride. Some of the solvents are also subjected to removal of impurities and dehydrated by distillation in coexistence with an alkali metal in an inert gas.

To prevent electrolyte 308 leakage, the electrolyte 308 can be formed into
15 a gel. Polymers which absorb the solvent of the electrolyte 308 and swell may be used as a gelling agent. For example, such polymers include poly(ethyleneoxide), poly(vinylalcohol), polyacrylamide, and the like.

The products of the present invention may be utilized to form fuel cells. A
fuel cell is a device for directly converting the chemical energy of a fuel into electrical
20 energy. There are various constructions of fuel cell devices, such as fuel cells, fuel cell groups or stacks, and fuel cell power plants which use hydrogen as the fuel for the respective fuel cell device. As is well known, an exothermic chemical reaction takes place in these fuel cell devices between hydrogen and an oxidant, for example, oxygen, resulting in the formation of water as the reaction product and the desired generation of
25 electricity. The incidental release of thermal energy exhibited as sensible heat is typically removed from the fuel cell. During the above reaction, hydrogen and the oxidant are consumed by the fuel cell. For the fuel cell device to continue its operation, hydrogen and the oxidant must be replenished at their respective consumption rates.

In some fuel cell applications, hydrogen is stored in tanks or similar
30 containers in its liquid or gaseous state in its pure form or in combination with inert substances. However, such containers are generally relatively large and heavy, and problematic when storage space and/or payload weight are limited. Thus, there is an

advantage when large amounts gaseous hydrogen can be stored in compact, relatively light weight containers.

Referring to Figure 24, a fuel cell 400 of the present invention comprises a housing 402, two gas diffusion electrodes, an anode 404 and a cathode 406, positioned within the housing 402 and respectively forming an anode side 408 and a cathode side 410, an electrolyte impregnated matrix or ion exchange membrane 409 positioned between and in electrical contact with the electrodes 404 and 406, an external circuit 412 electrically and operably connecting the anode 404 to the cathode 406 and a hydrogen storage unit 414 comprising products 416 of the present invention positioned within an enclosure 418 which is operably connected to the anode side 408. A catalyst layer is disposed on the electrolyte-facing surfaces of the respective electrodes 404 and 406. In the operation of the fuel cell 400, hydrogen gas is fed to the back side of the anode 404, and oxygen gas is fed to the back side of the cathode 406. The respective gases diffuse through the electrodes 404 and 406 and react at the catalyst sites to yield electrical energy, heat, and moisture.

On the anode side 408 of the fuel cell 400, hydrogen is electrochemically oxidized to give up electrons in accordance with the reaction: $2\text{H}_2 \rightarrow 4\text{H}^+ + 4\text{e}^-$. The electrical current so generated is conducted from the anode 404 through the external circuit 412 to the cathode 406. On the cathode side 410 of the fuel cell 400, the electrons are electrochemically combined with the oxidant in accordance with the reaction: $\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}$. The related flow of electrons through the electrolyte completes the circuit.

Referring additionally to Figures 1-19, the hydrogen storage unit 414 comprises the enclosure 418 and products 416 of the present invention having a substrate and either (1) a plurality of substantially aligned carbon nanotubes of a density greater than 10^4 nanotubes per square millimeter of substrate; (2) a plurality of substantially aligned carbon nanotubes of a density no greater than 10^2 nanotubes per square millimeter of a substrate; (3) one or more carbon nanotubes, wherein the substrate has a strain point or melting point temperature between about 300°C and 700°C ; (4) a plurality of substantially aligned carbon nanotubes originating and extending outwardly from an outer surface of the substrate; or (5) one or more free-standing carbon nanotubes originating and extending outwardly from an outer surface of the substrate. The carbon nanotubes have a hollow core and at least one diffusion path into the core. Preferably, the product

416 has plurality of substantially aligned carbon nanotubes of a density greater than 10^4 nanotubes per square millimeter of substrate with a high discontinuation density in the nanotube structure to provide a plurality of diffusion paths. Further, the carbon nanotubes of this product 416 can have an open end distal from the substrate. Particularly useful are
5 single-walled carbon nanotubes of the present invention which have a diameter of 1 nm. These nanotubes form bundles and are strong hydrogen gas absorbers. Hydrogen can be introduced into the carbon nanotube hollow core by placing the product 416 in a high pressure chamber (not shown) and introducing hydrogen gas at relatively high pressures into the chamber to diffuse hydrogen across the diffusion paths into the carbon nanotubes.
10 Also, hydrogen can be diffused into the nanotubes electropotentially or electrochemically. Further, heated products 416 can be placed into a hydrogen rich environment and allowed to cool, thereby drawing hydrogen into the nanotubes. Because the light-weight carbon nanotubes of the present invention have relatively large cores and surface areas, large amounts of hydrogen can be stored therein.

15 The products of the present invention can also be utilized to form composites with other dissimilar materials. Suitable dissimilar materials include metals, ceramics, glasses, polymers, graphite, and mixtures thereof. Such composites are prepared by coating the products of the present invention with these dissimilar materials in solid particulate form or in liquid form.

20 A variety of polymers, including thermoplastics and resins, can be utilized to form composites with the products of the present invention. Such polymers include, for example, polyamides, polyesters, polyethers, polyphenylenes, polysulfones, polyurethanes, or epoxy resins.

In another embodiment, the composite contains an inorganic material, e.g.,
25 a ceramic material or a glass. For example, a high-temperature copper oxide superconductor ceramic materials, such as BiSrCaCuO (BSCCO), TlBaCaCuO (TBCCO), $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$ (Bi-2212), $\text{Bi}_2\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ (Bi-2223), $\text{Tl}_2\text{Ba}_2\text{CuO}_6$ (Tl-2201), $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_8$ (Tl-2212), $\text{Tl}_2\text{Ba}_2\text{Ca}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ (Tl-2223), $\text{TlBa}_2\text{CaCu}_2\text{O}_7$ (1212), $\text{TlBa}_2\text{Ca}_2\text{Cu}_3\text{O}_9$ (Tl-1223), and any ceramic composition derived from these
30 compositions, such as partial replacement of Tl by Bi, Pb, Bi, or Pb. Ba by Sr, and Ca by Y or Cr., are useful in the present invention. These ceramics are deposited on the products of the present invention by magnetron sputtering, laser ablation, thermal spraying, electron beam evaporation, etc. to coat the substantially perpendicular, aligned

carbon nanotubes can form a high temperature superconducting material. Due to the high degree of nanotube alignment, excellent magnetic flux line core-pinning interaction can be obtained to enhance critical current densities (J_c) without destroying an unnecessary volume fraction of the superconductor.

5 As discussed in Yang et al., "Nanorod-Superconductor Composites: A Pathway to Materials with High Critical Current Densities," Science, 273: 1836-1840 (1996), incorporated herein by reference, large-scale applications of the high-temperature copper oxide superconductor ("HTSC") materials listed above require high J_c at temperatures near the boiling point of liquid nitrogen to be technologically useful. By
10 inserting columnar defects into the HTSC materials, high J_c can be maintained at higher temperatures when subjected to an electric current. The columnar defects can be accomplished by coating products of the present invention with the HTSC materials. Accordingly, a high temperature superconductor comprises a product having a substantially non-electrically conductive substrate and either (1) a plurality of
15 substantially aligned carbon nanotubes of a density greater than 10^4 nanotubes per square millimeter of substrate; (2) a plurality of substantially aligned carbon nanotubes of a density no greater than 10^2 nanotubes per square millimeter of a substrate; (3) one or more carbon nanotubes, wherein the substrate has a strain point or melting point temperature between about 300°C and 700°C ; (4) a plurality of substantially aligned
20 carbon nanotubes originating and extending outwardly from an outer surface of the substrate; or (5) one or more free-standing carbon nanotubes originating and extending outwardly from an outer surface of the substrate, a high-temperature copper oxide superconductor material in admixture with the product, and at least two spaced apart terminals connectable to an electric circuit, whereby the product and the high-temperature
25 copper oxide superconductor material admixture are subjectable to an electric current.

In still another embodiment, the composite includes a metal. Suitable metals include aluminum, magnesium, lead, zinc, copper, tungsten, titanium, niobium, hafnium, vanadium, and alloys thereof.

Referring to Figure 25 and generally to Figures 1-5B and 7-19, an
30 electromagnetic interference (EMI) shield 500 is formed from a product of the present invention comprising a substrate and either (1) a plurality of substantially aligned carbon nanotubes of a density greater than 10^4 nanotubes per square millimeter of substrate; (2) a plurality of substantially aligned carbon nanotubes of a density no greater than 10^2

nanotubes per square millimeter of a substrate; (3) one or more carbon nanotubes, wherein the substrate has a strain point or melting point temperature between about 300°C and 700°C; (4) a plurality of substantially aligned carbon nanotubes originating and extending outwardly from an outer surface of the substrate; or (5) one or more free-standing carbon nanotubes originating and extending outwardly from an outer surface of the substrate and a dissimilar material in admixture with the product. The dissimilar material comprises a polymer, graphite, or a combination thereof. Such polymers are thermoplastics and resins and can include, for example, polyamides, polyesters, polyethers, polyphenylenes, polysulfones, polyurethanes, or epoxy resins. The electromagnetic interference shield 500 is operationally positioned with respect to either an electromagnetic source 502 or an electronic component 504.

The composite can be used as an EMI shielding material in the construction of gaskets, housings for electronic components, including components within computers, conducting cables, and shielded rooms. EMI emission sources 502, and other applications known in the art. Depending upon the substrate selected for the product, such an EMI shield 500 is particularly useful in high temperature environments. In a process for shielding an electronic component 504 against EMI produced by the electromagnetic radiation source 502, the EMI shield 500 of the present invention is interposed between the electronic device 504 and the electromagnetic radiation source 502. Interference of the device 504 by the radiation source 502 is thereby substantially reduced or eliminated. A shielded electronic component 504 for resisting EMI generated by the electromagnetic source 502 has an electronic component 504 and a EMI shield 500 of the present invention operatively positioned with respect to the component 504. A shielded electromagnetic emission source 502 has an EMI emitting source 502 and EMI shield 500 of the present invention operatively positioned with respect to the source 502.

Still, the products of the present invention can as well be utilized to form a microelectrode 600, as shown in figure 26 and discussed in Stulik et al.,

“Microelectrodes: Definitions, Characterization and Hints For Their Use,” IUPAC Commission, 5: Document No. 550/61/97 (1999), incorporated herein by reference. The microelectrode 600 comprises a product having a substantially non-electrically conductive substrate 602 and either (1) a plurality of substantially aligned carbon nanotubes 604 of a density greater than 10^4 nanotubes per square millimeter of substrate; (2) a plurality of substantially aligned carbon nanotubes 604 of a density no greater than

10² nanotubes per square millimeter of a substrate; (3) one or more carbon nanotubes 604, wherein the substrate 602 has a strain point or melting point temperature between about 300°C and 700°C; (4) a plurality of substantially aligned carbon nanotubes 604 originating and extending outwardly from an outer surface of the substrate 602; or (5) one
5 or more free-standing carbon nanotubes 604 originating and extending outwardly from an outer surface 606 of the substrate 602 and at least one electrically conductive microfiber 608 operably connected to at least one carbon nanotube 604 of the product, wherein the at least one carbon nanotube 604 is operably and electrically connectable to an electric circuit.

10 Particularly well suited for use as an electrode or an array of electrodes are carbon nanotubes having open ends, as shown in Figure 13. The carbon nanotubes are grown on a non-electrically conductive substrate, such as glass, quartz, or a ceramic. The carbon nanotubes are operably and electrically connectable to an electric circuit with electrically conductive microfibers, such as, platinum or carbon microfibers, attached to
15 the nanotubes.

EXAMPLES

Example 1

20 Polished polycrystalline and single-crystal Ni substrates were placed into a chemical vapor deposition (CVD) chamber, and the pressure was reduced to $< 6 \times 10^{-6}$ Torr. Acetylene gas (99.99 % purity) and ammonia gas (99.99 % purity) were introduced into the chamber at a total flow rate of 120-200 standard cm³ per minute (sccm) and at a maintained working pressure of 1-20 Torr under the conditions listed in Table 1. After
25 stabilizing the working pressure, a tungsten filament coil powered by a DC source (a 0-500 V DC, 3 A power supply, Advanced Energy MDX 1.5K-magnetron drive) and a plasma-generator were energized to generate heat and plasma at a temperature below 666°C to induce carbon nanotube growth. Samples of the carbon nanotubes were examined by scanning electron microscopy (SEM, Hitachi S-4000) to measure tube
30 lengths, diameters, site distributions, alignment, density and uniformity. High-resolution transmission electron microscopy (TEM) was used to determine the microstructure of individual tubes. Further, the samples were also examined by x-ray diffraction. Raman

spectroscopy, and x-ray photoemission spectroscopy to study the structure, crystallinity, composition, and central core and tube wall structures.

Table 1. Growth conditions for the nanotubes shown in Figures 1(A), 1(B), 2, and 3.

| | C ₂ H ₂ / NH ₃ (sccm / sccm) | Filament Current (amperage, A) | Plasma Intensity (amperage / voltage / watts) | Growth Time (minutes) |
|----|------------------------------------------------------------------|-----------------------------------|--------------------------------------------------|--------------------------|
| 5 | | | | |
| 10 | (A): For Figures 1(A) and 1(B): 20 / 100 | 9 | 0.09 / 460 / 50 | 90 |
| 15 | (B): For Figure 2: 80 / 160 | 9 | 0.2 / 640 / 140 | 25 |
| 20 | (C): For Figure 3: 40 / 80 | 6 | 0.3 / 700 / 220 | 20 |

Figure 1A is a scanned image of an SEM micrograph showing the alignment of carbon nanotubes on polycrystalline nickel grown under the conditions described in Table 1(A). As observed, the carbon nanotubes are oriented perpendicular to the substrate surface and are quite uniform in height. The carbon nanotubes do not grow well along the Ni grain boundaries, shown by the two empty tracks running from upper left and from upper right down to bottom. This is probably due to the fact that grain boundaries do not have enough available nickel as a catalyst. Figure 1B is a higher magnification image of an area within a single nickel grain. Here, nanotube distribution uniformity within this grain is reasonably good. Although there is a wide distribution of carbon nanotube diameters ranging from 60 - 500 nm, the uniformity in both diameter and site distributions can be controlled via the growth conditions. Here, carbon nanotube density is about 10^6 nanotubes/mm².

Figure 2 is a scanned image of an SEM micrograph showing carbon nanotubes grown on polycrystalline nickel at a higher plasma intensity under the conditions listed in Table 1(B). Most of the nanotube diameters are smaller (~ 250 nm), and their distribution is narrower, ranging from 200 to 300 nm. With increased plasma intensity, the density increased to 4×10^6 nanotube/mm², about 4 times higher than that shown in Figure 1. The increase of plasma intensity apparently reduces the catalytic

nickel particle size, which leads to both thinner carbon nanotubes and improved nanotube uniformity.

Figure 3 is a scanned image of an SEM micrograph showing carbon nanotubes grown under the conditions listed in Table 1(C). These carbon nanotubes were synthesized at a higher plasma intensity than that used for the carbon nanotubes of Figure 2. In order to keep the substrates at low temperature, the filament current was reduced from 9 to 6 amperes. As shown in Figure 3, the carbon nanotubes are at least 10 μm long, and the diameters are < 100 nm. By increasing plasma intensity, two structural changes are readily observed. First, there is a substantial decrease in the average tube diameters from ~ 250 nm, as shown in Figure 2, to ~ 100 nm, as shown in Figure 3. Second, the tube lengths increase dramatically. This high growth rate is very attractive for the potential large-scale production of carbon nanotubes with long lengths. However, when the diameters are < 20 nm, the tubes are less straight than for those with diameters > 50 nm.

High resolution transmission electron microscopy (TEM) analysis of the carbon nanotubes shows these film structures to be truly carbon nanotubes, as opposed to carbon fiber-like structures. Samples with carbon nanotubes grown to several microns in length were scraped off a nickel substrate directly onto a copper TEM grid for analysis. Figure 4 shows a typical image obtained for these carbon nanotubes. The disorder is due entirely to the random process of nanotube collection on the TEM grid. The dark spot at the end of each structure is a cap of a small ball of catalyst layer material, nickel in the instant example. This image is typical to those reported elsewhere demonstrating a carbon nanotube structure. Nevertheless, the insert to Figure 4, a high-resolution image of a portion of a typical carbon nanotube structure, is more convincing. The width of this tube is ~ 30 nm and represents a highly defected multi-walled structure with a hollow core. The core diameter is about 20 nm and the wall thickness is about 5-10 nm. The fringes on each side of the tube identify individual cylindrical graphitic layers. This particular carbon nanotube is a structure with approximately 15 walls of graphitized carbon. Both the angular bend in the structure and the appearance of carbon walls running across the diameter of the nanotube demonstrate structural defects suggestive of twisting of the nanotube structure. As can be seen at the structural defects, non-continuous walls intersect one another. On an atomic scale, the defects create active surface sites for permeability through the nanotube structure. The lack of fringes inside

the nanotube, as well as the lighter contrast as compared to the nanotube walls, indicates that the core of the structure is hollow.

Example 2

Substrate Preparation

5 Display glass having a strain point temperature of 666°C was cut into 10 x 5 mm pieces and cleaned in acetone by ultra-sonication. The cleaned pieces were mounted onto the surface of a stainless steel resistive heater, and the whole assembly was placed into a magnetron sputtering chamber. The chamber was pumped down below 8×10^{-6} Torr before argon gas was introduced into the chamber to maintain a working
10 pressure of 20-60 mTorr. A nickel catalyst layer of 15 to 60 nm in thickness was deposited onto the glass substrates by magnetron sputtering for about 1.5 to 6 minutes. During deposition, the substrates were either heated or kept at room temperature.

 Catalyst layered substrates were placed to a CVD chamber, which was pumped down below 6×10^{-6} Torr. As soon as the chamber pressure reached 6×10^{-6}
15 Torr, acetylene and ammonia gases were introduced into the chamber to maintain a working pressure of 1 – 20 Torr during carbon nanotube growth. The total flow rate of acetylene and ammonia gases was 120 – 200 sccm with a volume ratio of acetylene to ammonia varying from 1: 2 to 1:10. After the working pressure stabilized, the power to the tungsten filament coil and to the plasma-generator, as described in Example 1, were
20 energized to generate heat and plasma at a temperature below 666°C to induce carbon nanotube growth under the conditions listed in Table 2. Carbon nanotube samples were examined in the manner described in Example 1. In particular, scanning electron microscopy was used to investigate the effect of various growth conditions on the morphology of carbon nanotubes grown on nickel-coated display glass.

25 As described in Table 2(A), NH_3 was introduced during the first 5 minutes without introducing C_2H_2 . During this time, the catalyst layer was plasma etched to reduce its thickness to less than 40 nm. After these initial 5 minutes, C_2H_2 was introduced. Immediately, a color change occurred as a result of the growth of carbon nanotubes. The growth period lasted only 10 minutes. Referring to Figures 5A-B, in
30 order to examine the orientation and alignment of the carbon nanotubes on the glass substrates, part of the carbon nanotube-covered area was peeled off (lower left in Figure 5A) with a tweezer to expose the glass substrate. During peeling, another area was crumpled (lower right in Figure 5A), and a long scratch was made on the peeled open

area (lower left in Figure 5A). Under visual and SEM observations, the alignment of the carbon nanotubes across the whole surface was as uniform as in the upper part of Figure 5A. To estimate the carbon nanotube length, an SEM was taken at higher magnification along the peeled edge (Figure 5B). Misalignment of the carbon nanotubes on the peeled edge resulted from the peeling operation. From Figure 5B, it was estimated that the nanotubes were about 100 nm in diameter and 20 μm in length. Given the growth time of 10 minutes, the growth rate was calculated to be 120 μm / hour, about 5 times faster than the value reported in Li.

As respectively shown in Figures 6A and 6B, the surfaces of the nickel layer after the initial NH_3 or N_2 plasma etching are essentially the same. The plasma etching conditions are respectively listed in Table 2(B) and 2(C). For comparison, Figure 6C shows the as-sputtered smooth nickel surface. Although both NH_3 and N_2 plasma etching roughen the nickel surface, the roughing of the nickel surface is not responsible for the nucleation and growth of carbon nanotubes.

Interestingly, when the sequence of gas introduction is reversed, that is, when C_2H_2 is introduced first, 5 minutes later, followed by NH_3 , no growth of carbon nanotubes is observed, only amorphous carbon is formed on the nickel surface. The amorphous carbon layer forms in the first 5 minutes and C_2H_2 plasma covered the nickel surface to inhibit the catalytic role of nickel so that there is no growth of carbon nanotubes. Apparently, carbon nanotubes grow only when catalyst gas (NH_3) is introduced first followed by the carbon source gas (C_2H_2) or both the carbon source and catalyst gases (C_2H_2 and NH_3 , respectively) are introduced simultaneously. Thus, it may be concluded that NH_3 plays a crucial catalytic role together with the nickel layer to promote the growth of the carbon nanotubes. The catalytic role of NH_3 is further confirmed by the fact that there is no carbon nanotube growth when NH_3 was replaced by N_2 gas at temperatures below 700°C with other conditions unchanged. However, carbon nanotubes do grow when NH_3 is replaced by N_2 at temperatures above 700°C utilizing PE-HF-CVD.

In order to examine the effect of thickness of the metal catalyst layer on the growth of carbon nanotubes, C_2H_2 and NH_3 were introduced at the same time under the conditions listed in Table 2(D). Under these growth conditions, no plasma etching occurred, and the nickel layer remained 40 nm thick.

Referring to Figure 7A, carbon nanotubes have an estimated site density of about 10^7 tubes/mm². The diameters of the carbon nanotubes (Figure 7A) are much larger than those in Figure 5B. From Figure 7B, it is estimated that the outside diameters of the carbon nanotubes range from 180 to 350 nm, and most of the carbon nanotubes are about 250 nm in diameter. Although not shown, carbon nanotubes have been grown in accordance with this method with diameters as large as 500 nm. This experiment clearly shows that as the catalyst layer thickness is reduced, the diameters of the resultingly grown carbon nanotubes are likewise reduced. As shown in Figure 7B, the catalytic role of nickel is also clearly indicated by the nickel cap on the tip of each nanotube.

Interestingly, one carbon nanotube, as indicated by an arrow in Figure 7B, does not have a nickel cap. Due to the absence of a cap on the identified nanotube, it may be concluded that the carbon nanotubes are empty with a very thin wall. In support of this conclusion, another carbon nanotube is viewable behind the capless one through its wall.

Surprisingly, the nanotubes have a central core which is larger than reported values in literature. These large carbon nanotubes may be useful for applications such as storage of gases, such as H₂, and as microelectrodes.

These experiments show a direct relationship between metal catalyst layer thickness and nanotube diameters. That is, the thinner the nickel layer, the thinner the nanotubes. To examine further the effect of nickel layer thickness on carbon nanotube growth, a much thinner nickel layer of only 15 nm is utilized under the conditions listed in Table 2(E) and 2(F). In one experiment (Table 2(F)), the nickel layer thickness is plasma etching reduced by introducing NH₃ first, and 20 minutes later introducing C₂H₂. In Figures 8A and 8B, respectively, SEM micrographs of carbon nanotubes grown under the conditions listed in Table 2(E) and 2(F) show the dependent relationship of nanotube diameter to the nickel layer thickness. The typical diameter of the nanotubes in Figure 8A is only about 65 nm, compared to 240 nm in Figure 7B. Relatively speaking, the alignment in Figure 8A is not quite as good as in Figure 7B. A comparison of Figures 8A and 8B demonstrates that 20 minutes of plasma etching reduces the thickness of nickel layer, which in turn results in even thinner carbon nanotubes with typical diameters of only about 20 nm. The comparison also shows that the alignment begins to deviate when the nanotube diameter is reduced to 20 nm. Carbon nanotubes have been produced in accordance with this method having a diameter as small as 4 nm. Therefore, for

applications requiring substantial nanotube alignment, it is apparent that diameters should be larger than 50 nm for carbon nanotubes having a length of 20 μm or longer.

Again, high-resolution TEM was utilized to determine the interior and wall structures of the carbon nanotubes. Samples for a plan view TEM were prepared as follows. Given the flexible nature of the nanotubes, the carbon nanotube film was penetrated with M-Bond 610 epoxy resin (M-Line Accessories) to provide mechanical stiffness. This resin has very low viscosity and curing is time/temperature dependent. Hydrotetrafuran (diethylene oxide) makes up about 90% of the composition of M-Bond. The carbon nanotube film was immersed in acetone; then M-Bond epoxy is slowly added until a 1:1 ratio is attained. The sample was cured at room temperature for 48 hours. Because the viscosity of the epoxy was very low when introduced to the sample, it easily impregnated the pores to completely mix with the acetone. Standard mechanical thinning and ion milling (low angle, low voltage and current) was used to thin the sample to electron transparency. Most of the substrate was removed mechanically, followed by ion milling until the film was exposed. Then, both sides were ion milled for 15 minutes.

Figure 9A shows a cross-sectional view of a typical thinner carbon nanotube. This carbon nanotube is a multi-walled central hollow tube with an outside diameter of nearly 30 nm. The fringes on each side of the tube represent individual cylindrical graphitic layers. This particular carbon nanotube has approximately 15 walls of graphitized carbon. Both the angular bend in the structure and the appearance of carbon walls running across the diameter of the nanotube demonstrate structural defects suggestive of twisting of the nanotube structure. The lack of fringes inside the tube, as well as the lighter contrast compared to the nanotube walls indicates that the core of the structure is hollow.

Further evidence of the hollow core is shown in Figure 9B. This is a high-resolution plan view TEM image of a single carbon nanotube structure. Here, the hollow nature of the nanotube, again represented by the lighter contrast of the inner core, is more readily observable. The disorder seen in the wall fringes circumventing the hollow center are most likely caused by the twist-like defects throughout the carbon nanotube length as shown in Figure 9A. These high-resolution TEM images show that the structures are hollow, multi-walled carbon nanotubes with defects existing along the tube. The defects of bending and twisting of the carbon nanotubes of the thin carbon nanotubes shown in Figures 9A and 9B are consistent with the SEM observation in Figure 8B. Further, there

is a inverse relationship between CVD temperature and defect density. As the deposition temperature is reduced, the carbon nanotubes demonstrate an increase in the number of defects which occur in the wall. On an atomic scale, these defects render the wall of the carbon nanotube discontinuous. This results in an extremely high, active, and accessible surface area due to the substantial alignment of and relatively large spacing between the carbon nanotubes. These discontinuations in the wall structure provide atomic disorder which results in an active surface through which atomic level diffusion can occur.

Table 2. Growth conditions for nanotubes shown in Figures 5, 6, 7, and 8.

| | C ₂ H ₂ / NH ₃ / N ₂ (sccm / sccm) | Filament Current (amperage, A) | Plasma Intensity (amperage / voltage / watts) | Growth Time (minutes) |
|--|-----------------------------------------------------------------------------------|-----------------------------------|--------------------------------------------------|--------------------------|
| | (A): For Figures 5A and 5B: | | | |
| | 0 / 160 / 0 | 8.5 | 0.10 / 635 / 72 | 5 |
| | followed by 80 / 160 / 0 | 8.5 | 0.13 / 670 / 95 | 10 |
| | (B): For Figure 6A: | | | |
| | 0 / 160 / 0 | 8.5 | 0.09 / 740 / 66 | 3 |
| | (C): For Figure 6B: | | | |
| | 0 / 0 / 296 | 8.5 | 0.10 / 480 / 53 | 3 |
| | (D): For Figures 7A and 7B: | | | |
| | 80 / 160 / 0 | 8.5 | 0.20 / 700 / 150 | 25 |
| | (E): For Figure 8A: | | | |
| | 40 / 160 / 0 | 7.2 | 0.13 / 650 / 90 | 14 |
| | (F): For Figure 8B: | | | |
| | 0 / 160 / 0 | 8.0 | 0.10 / 480 / 52 | 20 |
| | followed by 80 / 160 / 0 | 8.2 | 0.10 / 560 / 60 | 10 |

Example 3

A glass substrate was prepared as in Example 2 with a 10-40 nm thick nickel catalyst layer having an as-sputtered smooth surface, as shown in Figure 6C.

Carbon nanotubes were grown by PE-HF-CVD for about 10 minutes as in Examples 1 and 2, except the acetylene and ammonia volume ratio was 1:2 to 1:4. Figure 10 shows a large area growth of substantially vertically aligned carbon nanotubes. The length of the

carbon nanotubes is up to 50 μm . The diameters are estimated to be in the range of 100 – 150 nm (See Figure 14).

Example 4

Single crystal, p-type boron doped 9.5 $\Omega\text{-cm}$ (100) silicon substrates were prepared as in Example 2 with a 10-40 nm thick nickel catalyst layer having an as-sputtered smooth surface, as shown in Figure 6C. Carbon nanotubes were grown by PE-HF-CVD as in Examples 1 and 2, except the acetylene to ammonia volume ratio was 1:2 to 1:4. Figures 11 and 12 show carbon nanotubes which were grown for 5 and 2 minutes, respectively. Referring to Figure 11, substantially perpendicular carbon nanotube alignment is clearly shown. A nickel cap, which acts as a catalyst to sustain growth, is also discernible at the top of each carbon nanotube. Early stage carbon nanotube growth is shown Figure 12, since the growth was stopped at 2 minutes. The shortest nanotubes are about 0.1 μm .

Example 5

Carbon nanotubes were grown as in Example 3. The catalyst metal caps were thereafter removed by HNO_3 solution etching and Ar ion sputtering. Figures 13 and 14 show the SEM image of the nanotubes after removal of the nickel caps by HNO_3 solution etching and Ar ion sputtering, respectively. The solution etching by HNO_3 only took about one minute, and the removal of nickel caps is complete. As shown in Figure 13, the ends of the carbon nanotubes are open after etching. Morphologically, there was no observable damage by the HNO_3 etching. In Figure 14, all the nanotubes were bent by the Ar ion sputtering, and the nickel caps were not completely removed. These techniques may be utilized to remove any of the metal or metal alloy caps. By removing the caps, various fillings (i.e. hydrogen, lithium ions, bismuth, lead telluride, bismuth tritelluride, a pharmacological agent, etc.) can be added to the nanotube core. Thereafter, if desired, the open ends can be sealed by electrochemical deposition of a metal onto the carbon nanotubes.

Example 6

Carbon nanotubes were grown as in Example 3, except the substrates were placed in the CVD chamber at differing angles with respect to the plasma generator. Although the carbon nanotubes grew substantially aligned with one another, the alignment was independent of substrate surface topography. Figures 15 and 16 show the

SEM image taken from side and top on a sample sit tilted at a certain angle during growth. It is observed that carbon nanotube alignment is not perpendicular to the substrate surface, but rather is angled with respect to the substrate. The tilt direction is closely related to the direction of the electrical field which generates the plasma. This technique may be utilized to grow aligned carbon nanotubes at any angle with respect to the substrate, including nanotubes lying in a plane.

Example 7

A catalyst layer of nickel was deposited on a p-type boron doped 9.5 Ω -cm (100) silicon substrate by electron beam lithography and metal evaporation. A bilayer electron-beam resist (5% 100 molecular weight polymethylmethacralate) was capped by 2% 950 molecular weight polymethylmethacralate that was patterned with a JEOL J6400 SEM converted for lithography. The resist was developed in a solution of methyl isobutyl ketone and isopropyl alcohol (3:1). Thereafter, 150Å of nickel was deposited by electron beam evaporation. A catalyst layer (i.e. a large. $\sim 0.25 \text{ mm}^2$ nickel pad or one or more nano-dots) remained after resist/metal liftoff in acetone.

Carbon nanotubes were grown by PE-HF-CVD as in the process in Example 2, except growth was performed at a pressure of 1-10 Torr with an acetylene to ammonia volume mixture of 1:4 at a total flow rate of 200 sccm for about 5 minutes.

Referring to Figures 17A-B, scanned images of SEM micrographs show carbon nanotubes grown on the silicon substrate in the region of the edge of the nickel pad. As shown in Figure 17A, absence of nanotube growth in the foreground demonstrates selective growth on the nickel catalyst film and not on the silicon substrate. Figure 17B shows these nanotubes after being mechanically broken using tweezers. Surprisingly, the tubes break somewhere along the tube and not at the interface between the nickel and silicon. This observation is different that that of nickel-on-glass nanotube growth, where the nanotubes broke cleanly at the nickel-glass interface, as shown in Figure 5A.

Example 8

Nickel catalyst nano-dot patterns were deposited on a p-type boron doped 9.5 Ω -cm (100) silicon substrate by electron beam lithography and metal evaporation as in Example 7. Carbon nanotubes were grown by PE-HF-CVD as in the process in Example 7, except the growth temperature was between 300°C and 666°C and only a

single, free-standing carbon nanotube grew on each nickel nano-dot. Thereafter, carbon samples were examined by SEM, TEM, XPS, etc. techniques as discussed above.

Figure 18 is a series of SEM micrographs illustrating the growth of single, multiwall carbon nanotube obelisks on respective nickel catalyst nano-dots. The catalyst nano-dots are shown in arrays of ~100 nm catalyst nano-dots. The site and spacing are precisely controlled. Figures 18A, 18C, 18E, and 18F are perspective views of the nanotubes, and Figures 18B and 18D are top views of the nanotubes. Figures 18A and 18B demonstrate selective growth of the nanotubes on the several repeated array patterns. The nanotubes accurately reflect the spacing and periodicity of the lithographically patterned catalyst nano-dots. Figures 18C and 18D reflect higher magnification and show the repeated array pattern where the nanotubes are spaced either 2 μm apart (left portion of array) or 1 μm apart (right portion of array).

The sharp, tapered tips of the nanotubes shown in Figures 18E, 18F, and 19 are unique to carbon nanotubes grown on nano-dots under the instant conditions. Notably, such nanotubes do not have a cap of the catalyst material. In Figure 18F, the nano-dots are spaced 5 μm apart. The non-uniformity of height (0.1 to 5 μm) is apparently not related to the spatial position. Rather, it is believed to be due to non-uniform electron beam lithography and electron beam evaporation of the catalyst nano-dots onto the substrate. With precise control of the electron beam lithography, all carbon nanotubes should be substantially uniform in height. Nanotube length is dependent upon the growth time and the thickness of the nano-dot, whereas nanotube diameter depends upon the diameter of the nano-dot. It can be observed that although the heights vary, the diameters are generally uniform at ~150 nm. By utilizing controlled nano-dot placement on the substrate, single or multiple carbon nanotubes with controlled site density can be achieved. For example, the direct growth of a single carbon nanotube on the probe tip of scanning tunneling microscope (STM), atomic force microscope (AFM), etc. may be achieved. Well-defined spacing of multiple carbon nanotubes with multi-electron beam lithography can improve the patterning ability by $10^4 - 10^6$ times.

Although the invention has been described in detail for the purpose of illustration, it is understood that such detail is solely for that purpose, and variations can be made therein by those skilled in the art without departing from the spirit and scope of the invention which is defined by the following claims.

WHAT IS CLAIMED:

1. A product comprising a plurality of substantially aligned carbon nanotubes attached to a substrate at a density greater than 10^4 nanotubes per square millimeter of substrate.
5
2. A product as claimed in claim 1, wherein the carbon nanotubes extend outwardly from and substantially perpendicular to the substrate.
3. A product as claimed in claim 1, wherein the carbon nanotubes extend outwardly from and at a non-perpendicular angle with respect to the substrate.
- 10 4. A product as claimed in claim 1, wherein the carbon nanotubes extend substantially parallel to the substrate.
5. A product as claimed in claim 1, wherein the nanotubes have a diameter between 4 to 500 nanometers.
- 15 6. A product as claimed in claim 1, wherein the nanotubes have a diameter of at least 50 nanometers.
7. A product as claimed in claim 1, wherein the substrate has a strain point or melting point temperature up to 3000°C .
8. A product as claimed in claim 1, wherein the substrate has a strain point or melting point temperature of at least about 300°C .
- 20 9. A product as claimed in claim 1, wherein the substrate comprises glass, silica, quartz, silicon, iron, cobalt, nickel, an alloy of iron, cobalt, or nickel, platinum, a ceramic, or a combination thereof.
10. A product as claimed in claim 9, wherein the substrate is a glass plate.
11. A product as claimed in claim 9, wherein the substrate is a silicon wafer.
- 25 12. A product as claimed in claim 1, wherein substantially all carbon nanotubes have a cap distal from the substrate comprising a metal or a metal alloy.

13. A product as claimed in claim 12, wherein the cap is iron, cobalt, nickel, or an alloy of iron, cobalt, or nickel.
14. A product as claimed in claim 13, wherein the cap is nickel.
15. A product as claimed in claim 1, further comprising a filling within the carbon
5 nanotubes.
16. A product as claimed in claim 1, wherein substantially all carbon nanotubes have an open end.
17. A product as claimed in claim 16, further comprising a filling within the carbon nanotubes.
- 10 18. A product as claimed in claim 17, wherein the filling is hydrogen, lithium ions, bismuth, lead telluride, or bismuth tritelluride.
19. A product as claimed in claim 17, wherein the filling is a pharmacological agent.
20. A product as claimed in claim 17, wherein the filling is enclosed within the carbon nanotubes.
- 15 21. A product comprising a plurality of substantially aligned carbon nanotubes attached to a substrate at a density no greater than 10^2 nanotubes per square millimeter of substrate.
22. A product as claimed in claim 21, wherein the carbon nanotubes extend outwardly from and substantially perpendicular to the substrate.
- 20 23. A product as claimed in claim 21, wherein the carbon nanotubes extend outwardly from and at a non-perpendicular angle with respect to the substrate.
24. A product as claimed in claim 21, wherein the carbon nanotubes extend substantially parallel to the substrate.
25. A product as claimed in claim 21, wherein the nanotubes have a diameter between
25 4 to 500 nanometers.

26. A product as claimed in claim 21, wherein the nanotubes have a diameter of at least about 50 nanometers.
27. A product as claimed in claim 21, wherein the substrate has a strain point or melting point temperature up to 3000°C.
- 5 28. A product as claimed in claim 21, wherein the substrate has a strain point or melting point temperature of at least about 300°C.
29. A product as claimed in claim 21, wherein the substrate comprises glass, silica, quartz, silicon, iron, cobalt, nickel, an alloy of iron, cobalt, or nickel, platinum, a ceramic, or a combination thereof.
- 10 30. A product as claimed in claim 29, wherein the substrate is a glass plate.
31. A product as claimed in claim 29, wherein the substrate is a silicon wafer.
32. A product as claimed in claim 21, further comprising a filling within the carbon nanotubes.
33. A product as claimed in claim 21, wherein substantially all carbon nanotubes have
15 an open end.
34. A product as claimed in claim 33, further comprising a filling within the carbon nanotubes.
35. A product as claimed in claim 34, wherein the filling is hydrogen, lithium ions, bismuth, lead telluride, bismuth tritelluride, or a pharmacological agent.
- 20 36. A product as claimed in claim 34, wherein the filling is enclosed within the carbon nanotubes.
37. A product comprising a substrate having a strain point or a melting point temperature between about 300°C and 700°C and one or more carbon nanotubes.
38. A product comprising a substrate having an outer surface and a plurality of
25 substantially aligned carbon nanotubes originating and extending outwardly from the outer surface.

39. A product comprising a substrate having an outer surface and one or more free-standing carbon nanotubes originating and extending from the outer surface.
40. A method of forming a product with one or more carbon nanotubes on a substrate comprising:
- 5 providing a substrate in a reduced pressure environment containing a carbon source gas and a catalyst gas and
- exposing the substrate to a plasma under conditions effective to cause formation and growth of one or more carbon nanotubes on the substrate.
41. A method according to claim 40, wherein the reduced pressure environment has a
10 pressure between about 0.1 to about 100 Torr.
42. A method according to claim 41, wherein the reduced pressure environment has a pressure between about 1 to about 20 Torr.
43. A method according to claim 40, wherein the product has a strain point or melting point temperature between 300°C and 3000°C.
- 15 44. A method according to claim 40, wherein the substrate comprises glass, silica, quartz, mesoporous silicon, silicon, iron, cobalt, nickel, an alloy of iron, cobalt, or nickel, platinum, a ceramic, or a combination thereof.
45. A method according to claim 44, wherein the substrate is a glass plate.
46. A method according to claim 44, wherein the substrate is a silicon wafer.
- 20 47. A method according to claim 40, wherein the carbon source gas is a saturated or unsaturated linear, branched, or cyclic carbon and hydrogen compound having up to six carbon atoms.
48. A method according to claim 47, wherein the carbon source gas is acetylene, ethylene, or benzene.
- 25 49. A method according to claim 40, wherein the catalyst gas is ammonia or nitrogen.

50. A method according to claim 40, wherein the volume ratio of carbon source gas to catalyst gas ranges from about 1:2 to about 1:10.
51. A method according to claim 40, wherein the substrate is exposed to the plasma at a temperature below 700°C.
- 5 52. A method according to claim 40, wherein the substrate is exposed to the plasma at a temperature above about 300°C.
53. A method according to claim 40, wherein the substrate is exposed to the plasma at a temperature between 300°C and 3000°C.
54. A method according to claim 40, further comprising:
- 10 disposing a catalyst film onto the substrate by radio frequency magnetron sputtering prior to said providing the substrate in a reduced pressure environment containing a carbon source gas and a catalyst gas.
55. A method according to claim 40, wherein the substrate has a catalyst film disposed thereon.
- 15 56. A method according to claim 55, wherein the film has a thickness of at least about 15 nanometers.
57. A method according to claim 55, wherein the film is nickel, iron, cobalt, or an alloy of nickel, iron, or cobalt.
58. A method according to claim 57, wherein the film is nickel.
- 20 59. A method according to claim 55, further comprising:
- varying the carbon nanotube diameter in direct proportion to the film thickness.
60. A method according to claim 40, further comprising:
- disposing a catalyst nano-dot onto the substrate by electron beam evaporation, thermal evaporation, or magnetron sputtering prior to said providing the substrate in a
- 25 reduced pressure environment containing a carbon source gas and a catalyst gas.

61. A method according to claim 60, wherein each nano-dot forms one carbon nanotube.
62. A method according to claim 40, wherein the substrate has at least one catalyst nano-dot disposed thereon.
- 5 63. A method according to claim 62, wherein each nano-dot forms one carbon nanotube.
64. A method according to claim 62, wherein the at least one nano-dot is nickel, iron, cobalt, or an alloy of nickel, iron, or cobalt.
65. A method according to claim 64, wherein the at least one nano-dot comprises
10 nickel.
66. A method according to claim 40, further comprising:
varying the carbon nanotube diameter in inverse proportion to the plasma intensity.
67. A method according to claim 40, further comprising:
15 varying the carbon nanotube length in direct proportion to the plasma intensity.
68. A method according to claim 40, wherein the one or more carbon nanotubes have a cap, and further comprising:
removing the cap from the one or more carbon nanotubes to form open-end on the one or more carbon nanotubes.
- 20 69. A method according to claim 68, wherein the cap is removed by HNO_3 solution etching.
70. A method according to claim 68, wherein the cap is removed by argon ion sputtering.
71. A method according to claim 68, further comprising:

adding a filling into the one or more carbon nanotubes after said removing the cap.

72. A method according to claim 71, further comprising:

5 enclosing the open-ends of the one or more carbon nanotubes after said adding a filling to store the filling within the one or more carbon nanotubes.

73. A method according to claim 72, wherein the open-ends of the one or more carbon nanotubes are enclosed by electrochemical deposition or magnetron sputtering of a metal onto the one or more carbon nanotubes.

10 74. A method according to claim 40, wherein the one or more carbon nanotubes have a closed end and further comprising:

exposing the one or more carbon nanotubes to oxygen under conditions effective to remove the closed end.

75. A method according to claim 74, further comprising:

adding a filling into the one or more carbon nanotubes.

15 76. A method according to claim 74, further comprising:

enclosing the one or more carbon nanotubes after said adding a filling to store the filling within the one or more carbon nanotubes.

20 77. A method according to claim 76, wherein the one or more carbon nanotubes are enclosed by electrochemical deposition or magnetron sputtering of a metal onto the one or more carbon nanotubes.

78. A field emission display comprising:

a baseplate having an electron emitting array positioned thereon and

25 a phosphor coated plate spaced apart from the baseplate so that electrons emitted from the array impinge on the phosphor coating, wherein the baseplate comprises a substrate and either (1) a plurality of substantially aligned carbon nanotubes of a density greater than 10^4 nanotubes per square millimeter of substrate; (2) a plurality of

substantially aligned carbon nanotubes of a density no greater than 10^2 nanotubes per square millimeter of a substrate; (3) one or more carbon nanotubes, wherein the substrate has a strain point or melting point temperature between about 300°C and 700°C; (4) a plurality of substantially aligned carbon nanotubes originating and extending outwardly from an outer surface of the substrate; or (5) one or more free-standing carbon nanotubes originating and extending outwardly from an outer surface of the substrate.

79. An electron emitter comprising:

an electron generating source and

a product having at least one carbon nanotube operably connected to the electron generating source to emit electrons from the at least one carbon nanotube, wherein the product comprises a substrate and either (1) a plurality of substantially aligned carbon nanotubes of a density greater than 10^4 nanotubes per square millimeter of substrate; (2) a plurality of substantially aligned carbon nanotubes of a density no greater than 10^2 nanotubes per square millimeter of substrate; (3) one or more carbon nanotubes, wherein the product has a strain point or melting point temperature between about 300°C and 700°C; (4) a plurality of substantially aligned carbon nanotubes originating and extending outwardly from an outer surface of the substrate; or (5) one or more free-standing carbon nanotubes originating and extending outwardly from an outer surface of the substrate.

80. A scanning electron microscope comprising:

a vacuum chamber capable of receiving a specimen;

an electron source for producing electrons;

a probe for emitting and directing the electrons toward and scanning the specimen

operably disposed within the vacuum chamber;

a detector operably positioned within the vacuum chamber for collecting radiation issuing from the specimen as a result of scanning by the probe to produce an output signal; and

a display screen operably connected to the detector to display an image of the area of the specimen scanned by the probe, wherein the probe comprises a substrate and either (1) a plurality of substantially aligned carbon nanotubes of a density greater than 10^4 nanotubes per square millimeter of substrate; (2) a plurality of substantially aligned carbon nanotubes of a density no greater than 10^2 nanotubes per square millimeter of a

substrate; (3) one or more carbon nanotubes, wherein the substrate has a strain point or melting point temperature between about 300°C and 700°C; (4) a plurality of substantially aligned carbon nanotubes originating and extending outwardly from an outer surface of the substrate; or (5) one or more free-standing carbon nanotubes originating and extending outwardly from an outer surface of the substrate.

81. A battery comprising:

an anode;

a cathode;

an insulator disposed between the anode and the cathode; and
an electrolyte,

wherein at least one of the anode and the cathode comprise a product having a substrate and either (1) a plurality of substantially aligned carbon nanotubes of a density greater than 10^4 nanotubes per square millimeter of substrate; (2) a plurality of substantially aligned carbon nanotubes of a density no greater than 10^2 nanotubes per square millimeter of a substrate; (3) one or more carbon nanotubes, wherein the substrate has a strain point or melting point temperature between about 300°C and 700°C; (4) a plurality of substantially aligned carbon nanotubes originating and extending outwardly from an outer surface of the substrate; or (5) one or more free-standing carbon nanotubes originating and extending outwardly from an outer surface of the substrate.

82. A fuel cell comprising:

a housing;

a gas diffusion anode positioned within the housing to form an anode side;

a gas diffusion cathode positioned within the housing to form a cathode side;

an electrolyte impregnated matrix or ion exchange membrane positioned between and in electrical contact with the anode and the cathode;

an external circuit electrically and operably connecting the anode to the cathode;

and

an enclosed hydrogen storage unit operably connected to the anode side comprising a product having a substrate and either (1) a plurality of substantially aligned carbon nanotubes of a density greater than 10^4 nanotubes per square millimeter of substrate; (2) a plurality of substantially aligned carbon nanotubes of a density no greater

than 10^2 nanotubes per square millimeter of a substrate; (3) one or more carbon nanotubes, wherein the substrate has a strain point or melting point temperature between about 300°C and 700°C ; (4) a plurality of substantially aligned carbon nanotubes originating and extending outwardly from an outer surface of the substrate; or (5) one or more free-standing carbon nanotubes originating and extending outwardly from an outer surface of the substrate, wherein substantially all carbon nanotubes have at least one diffusion path; and

hydrogen gas disposed within the carbon nanotubes.

83. A composite comprising:

a product comprising a substrate and either (1) a plurality of substantially aligned carbon nanotubes of a density greater than 10^4 nanotubes per square millimeter of substrate; (2) a plurality of substantially aligned carbon nanotubes of a density no greater than 10^2 nanotubes per square millimeter of a substrate; (3) one or more carbon nanotubes, wherein the substrate has a strain point or melting point temperature between about 300°C and 700°C ; (4) a plurality of substantially aligned carbon nanotubes originating and extending outwardly from an outer surface of the substrate; or (5) one or more free-standing carbon nanotubes originating and extending outwardly from an outer surface of the substrate and

a dissimilar material in admixture with the product, wherein the dissimilar material is selected from the group consisting of metal, ceramic, glass, polymer, graphite, and mixtures thereof.

84. A high temperature superconductor comprising:

a product having a substantially non-electrically conductive substrate and either (1) a plurality of substantially aligned carbon nanotubes of a density greater than 10^4 nanotubes per square millimeter of substrate; (2) a plurality of substantially aligned carbon nanotubes of a density no greater than 10^2 nanotubes per square millimeter of a substrate; (3) one or more carbon nanotubes, wherein the substrate has a strain point or melting point temperature between about 300°C and 700°C ; (4) a plurality of substantially aligned carbon nanotubes originating and extending outwardly from an outer surface of the substrate; or (5) one or more free-standing carbon nanotubes originating and extending outwardly from an outer surface of the substrate,

a high-temperature copper oxide superconductor material in admixture with the product, and

at least two spaced apart terminals electrically connected to the admixture of the product and the high-temperature copper oxide superconductor material and engagable
5 with an electric circuit.

85. An electromagnetic interference (EMI) shield comprising:

a product comprising a substrate and either (1) a plurality of substantially aligned carbon nanotubes of a density greater than 10^4 nanotubes per square millimeter of
10 substrate; (2) a plurality of substantially aligned carbon nanotubes of a density no greater than 10^2 nanotubes per square millimeter of a substrate; (3) one or more carbon nanotubes, wherein the substrate has a strain point or melting point temperature between about 300°C and 700°C; (4) a plurality of substantially aligned carbon nanotubes
originating and extending outwardly from an outer surface of the substrate; or (5) one or
15 more free-standing carbon nanotubes originating and extending outwardly from an outer surface of the substrate and

a dissimilar material in admixture with the product, wherein the dissimilar material is a polymer, graphite, or a combination thereof, wherein said electromagnetic interference shield is operationally positioned with respect to either an electromagnetic
20 source or an electronic component.

86. A microelectrode comprising:

a product comprising a substantially non-electrically conductive substrate and either (1) a plurality of substantially aligned carbon nanotubes of a density greater than
25 10^4 nanotubes per square millimeter of substrate; (2) a plurality of substantially aligned carbon nanotubes of a density no greater than 10^2 nanotubes per square millimeter of a substrate; (3) one or more carbon nanotubes, wherein the substrate has a strain point or melting point temperature between about 300°C and 700°C; (4) a plurality of
substantially aligned carbon nanotubes originating and extending outwardly from an outer
30 surface of the substrate; or (5) one or more free-standing carbon nanotubes originating and extending outwardly from an outer surface of the substrate and

at least one electrically conductive microfiber operably connected to at least one carbon nanotube of the product, wherein the at least one carbon nanotube is operably and electrically connectable to an electric circuit.

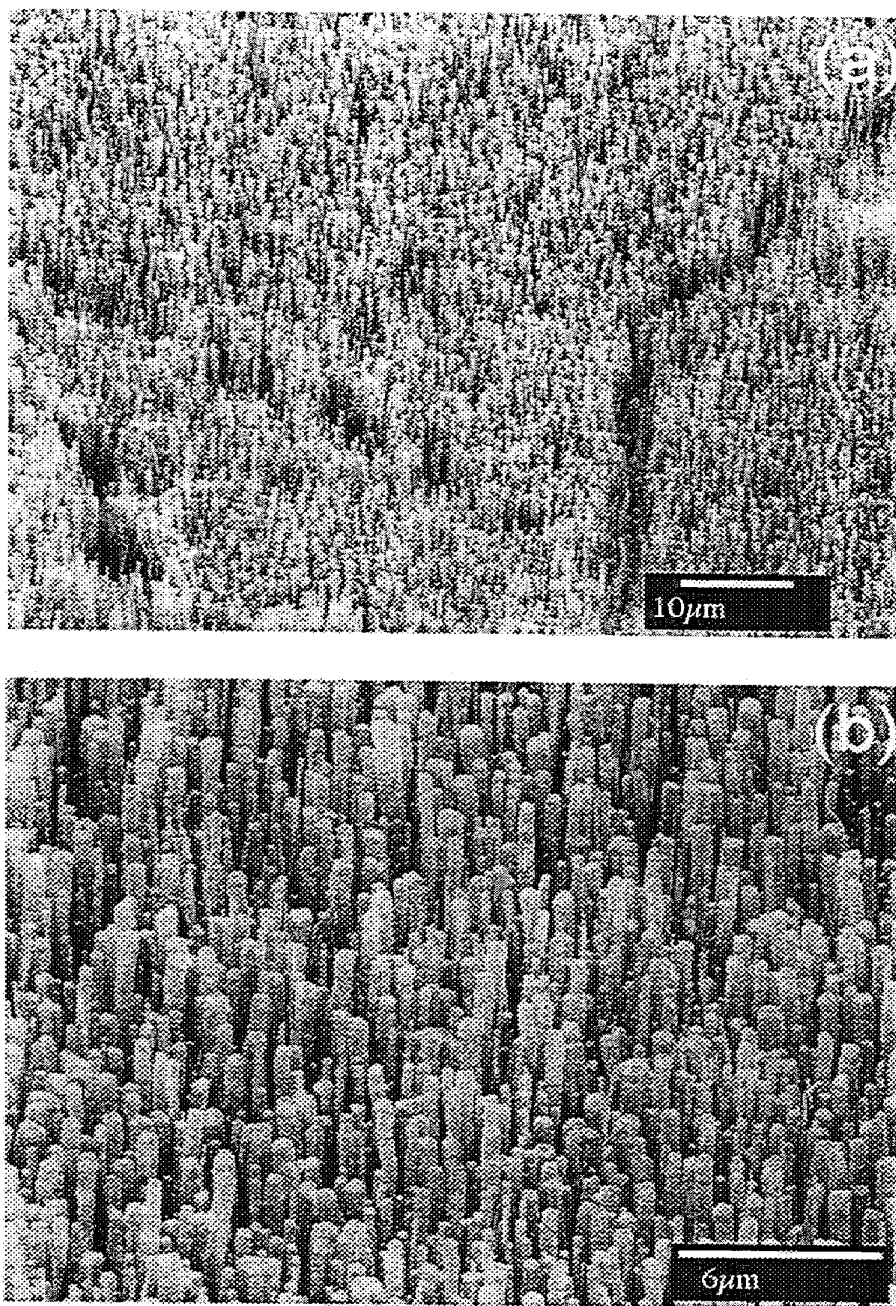


Fig. 1

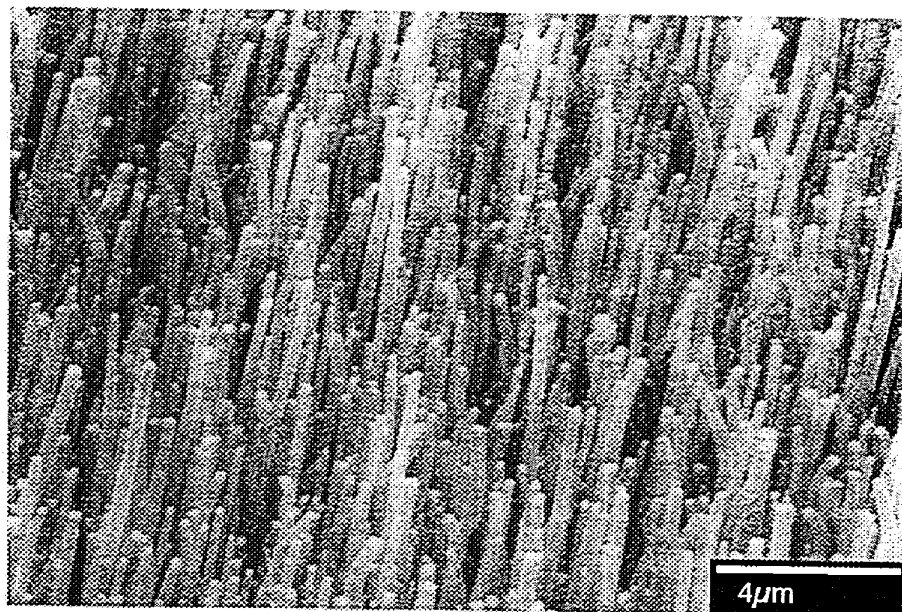


Fig. 2

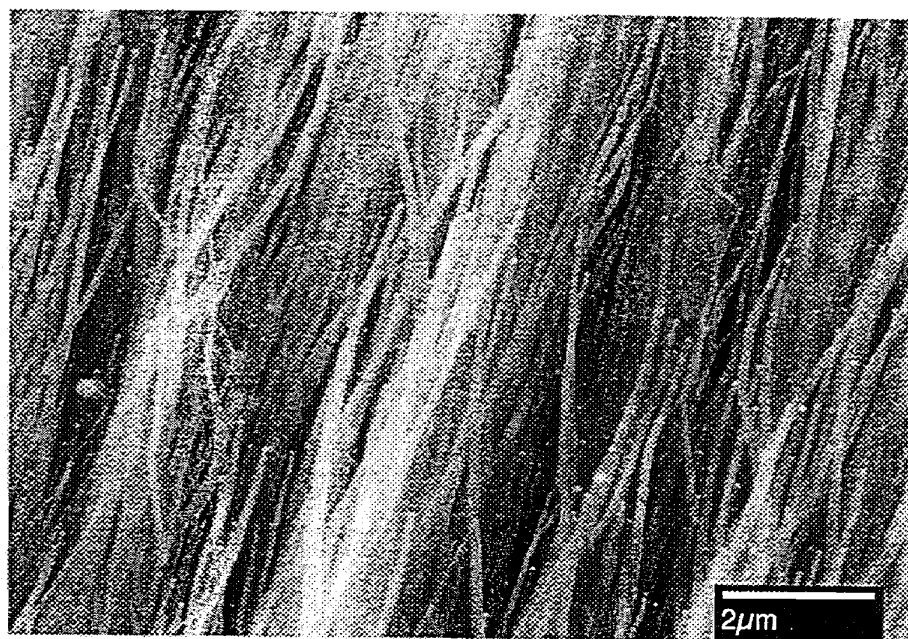


Fig. 3

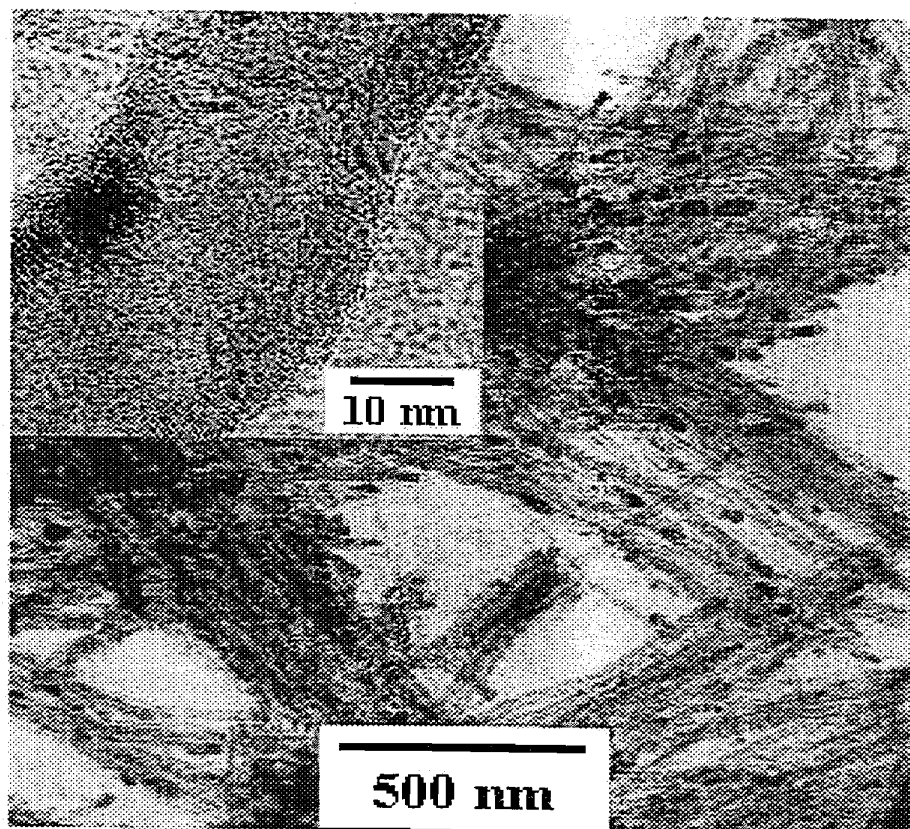


Fig. 4

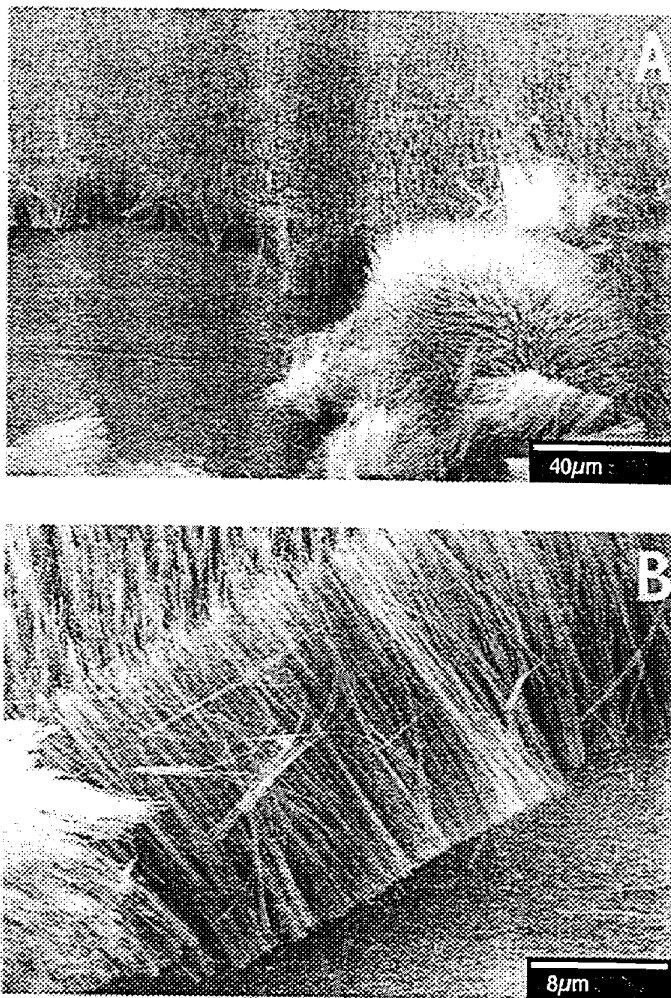


Fig. 5

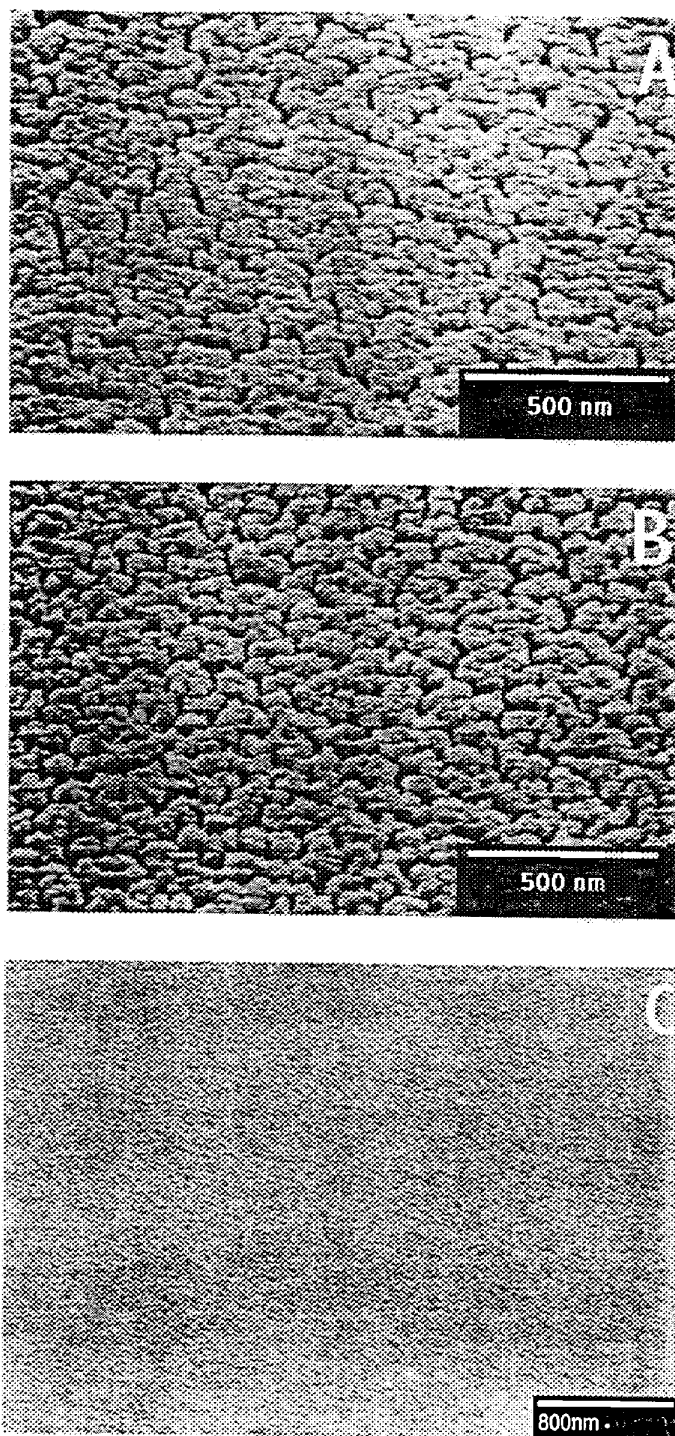
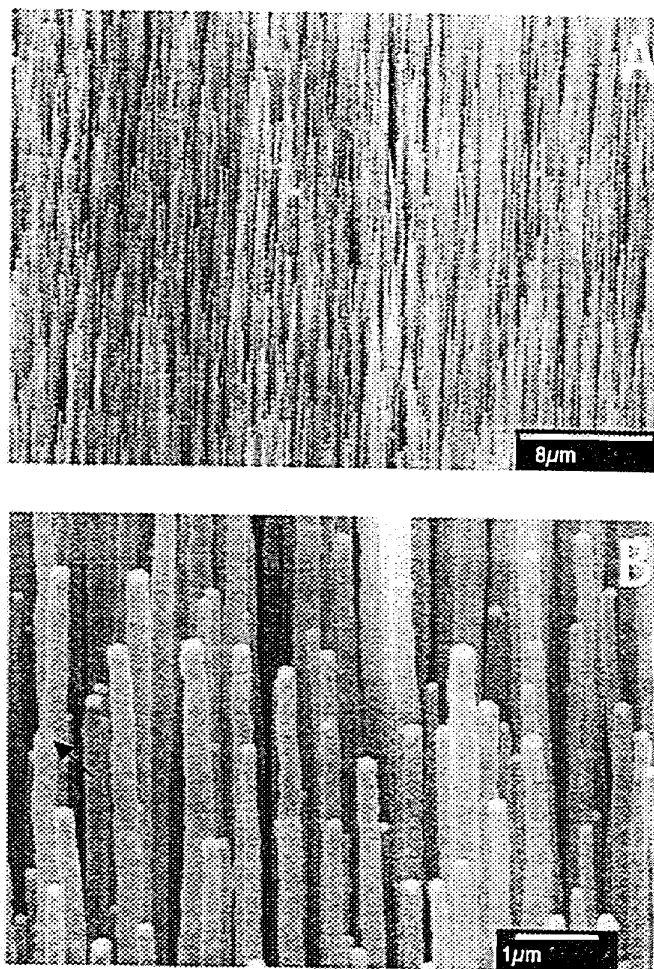


Fig. 6

**Fig. 7**

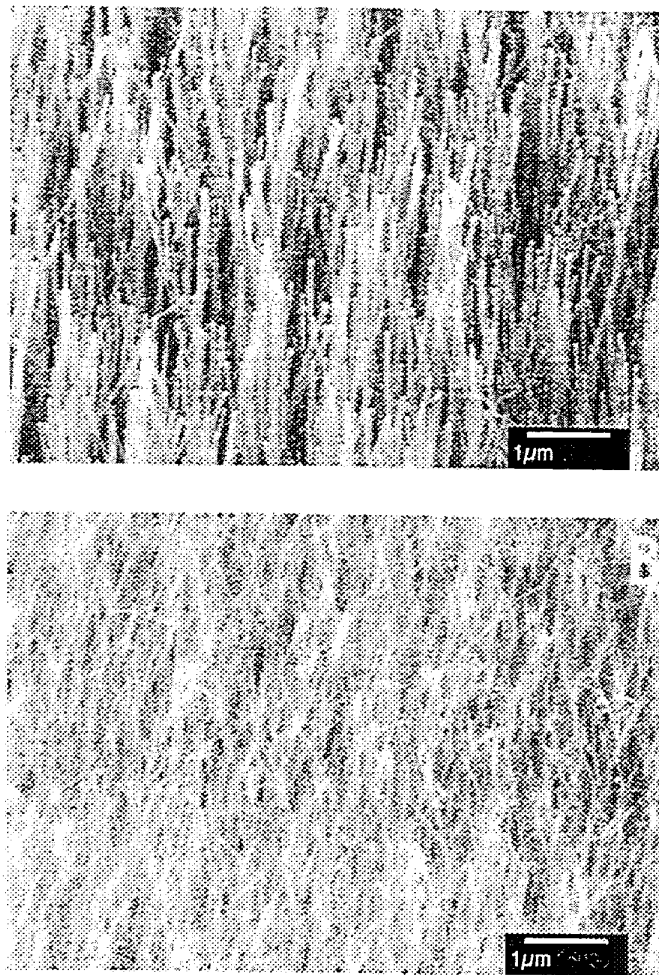


Fig. 8

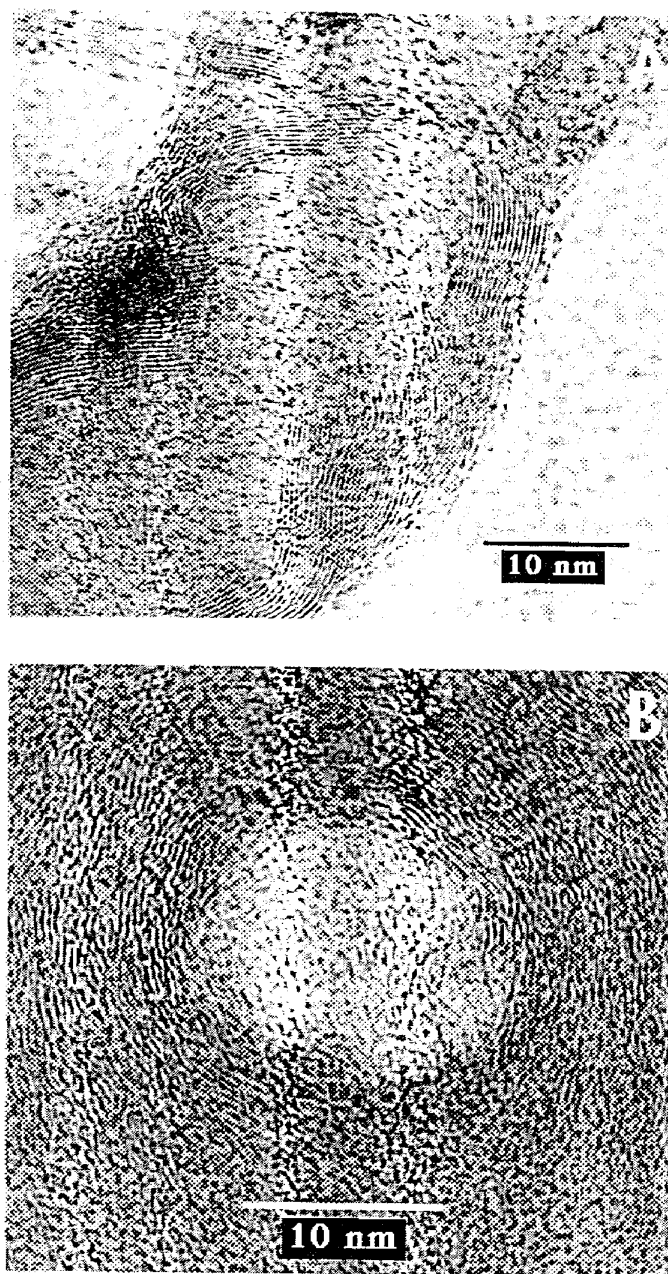


Fig. 9

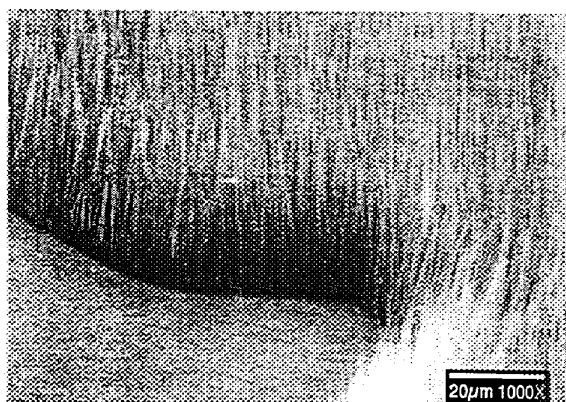


Fig. 10

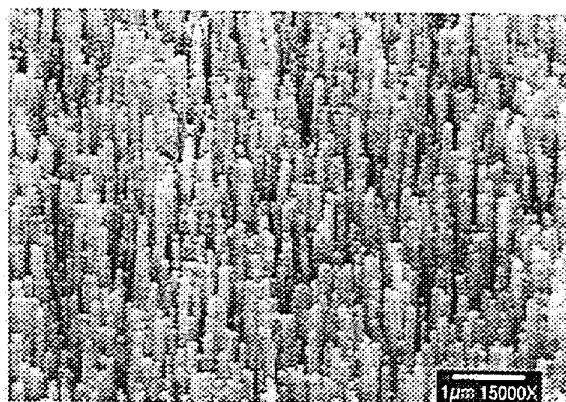


FIG. 11

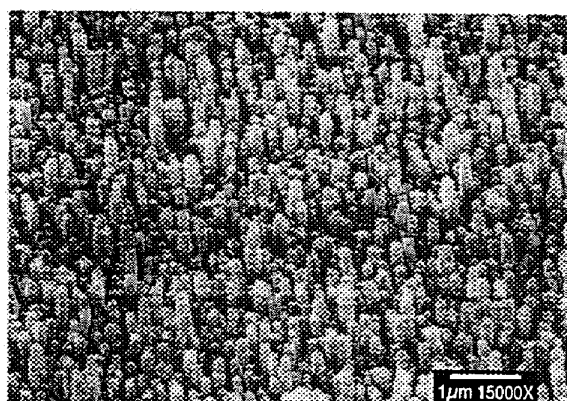


FIG. 12

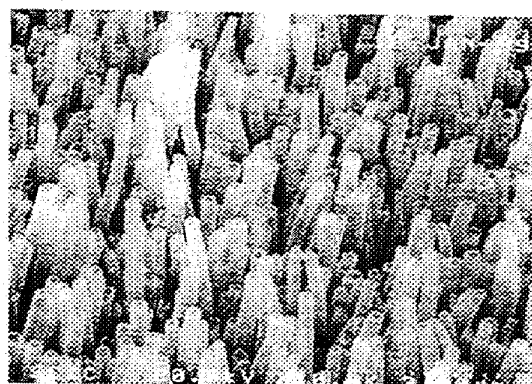


FIG. 13

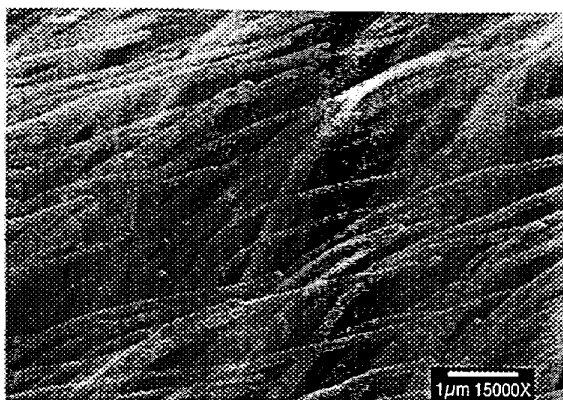


FIG. 14

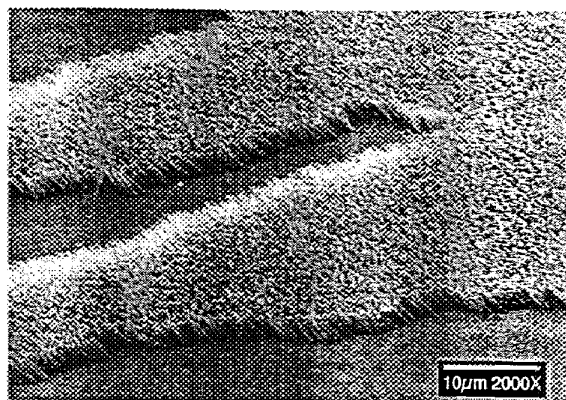


FIG. 15

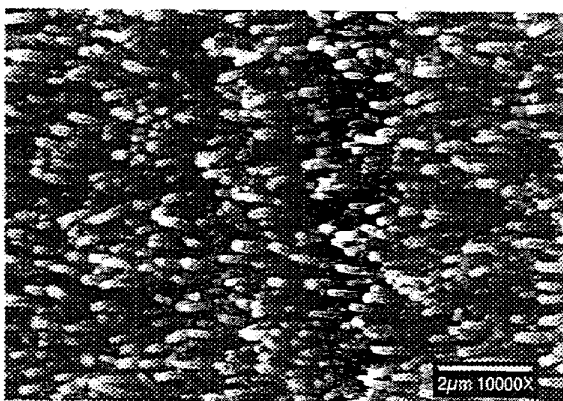


FIG. 16

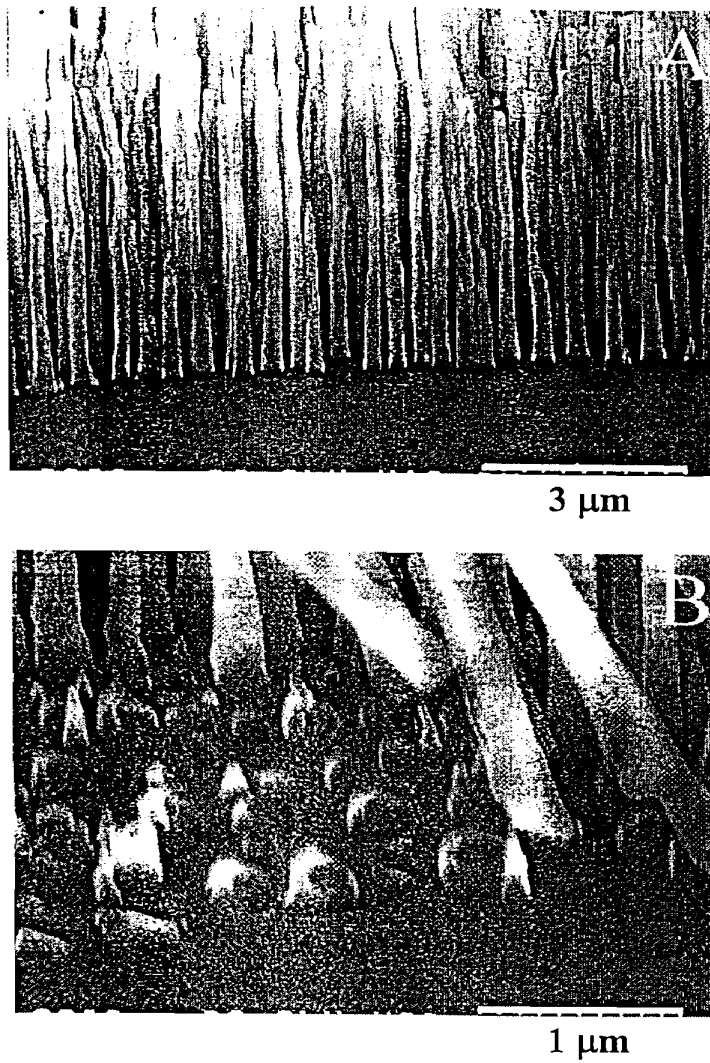


Fig. 17

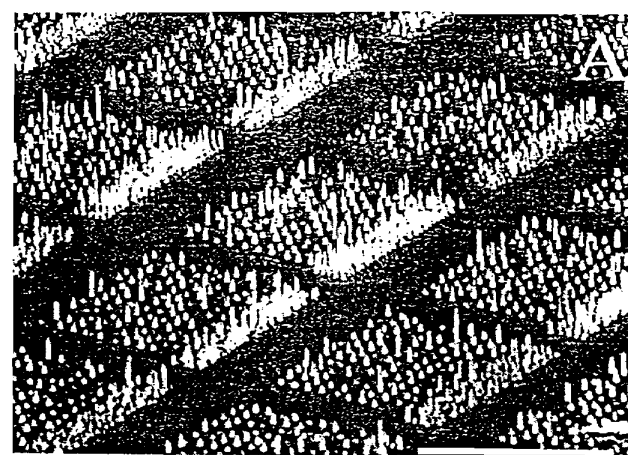
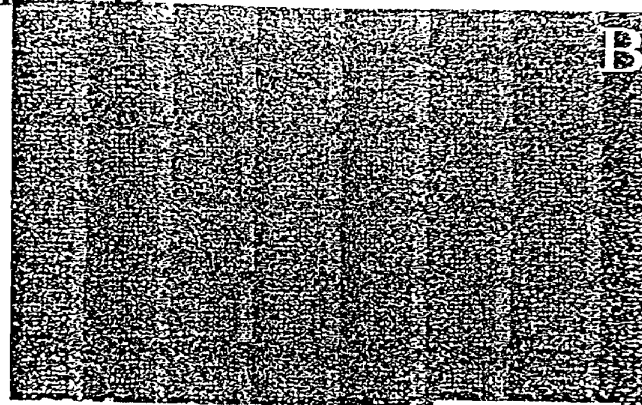
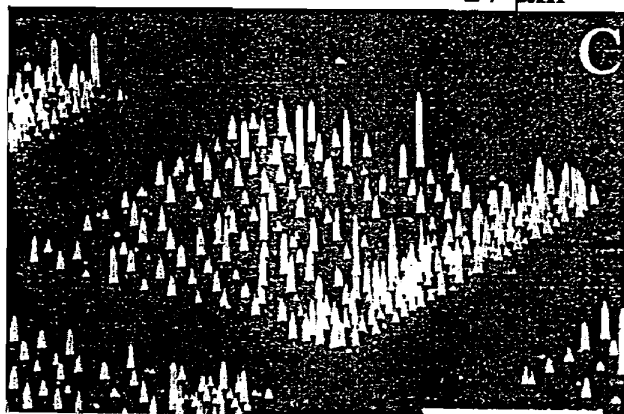
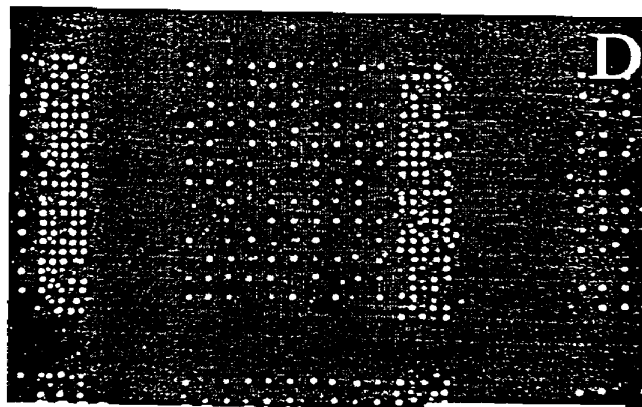
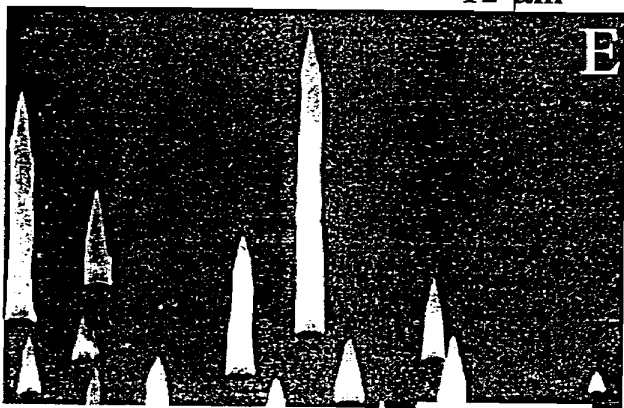
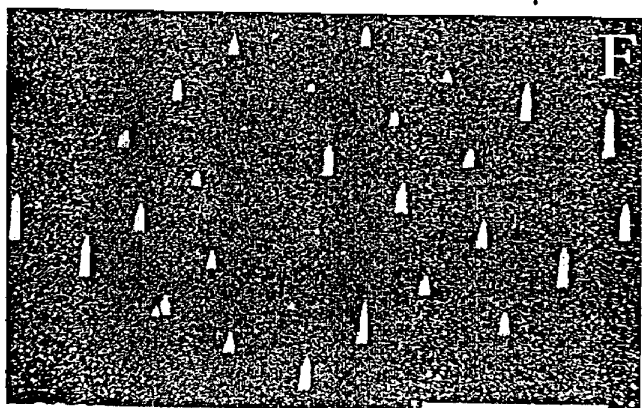
27 μm 86 μm 12 μm 20 μm 3 μm 10 μm

Fig. 18

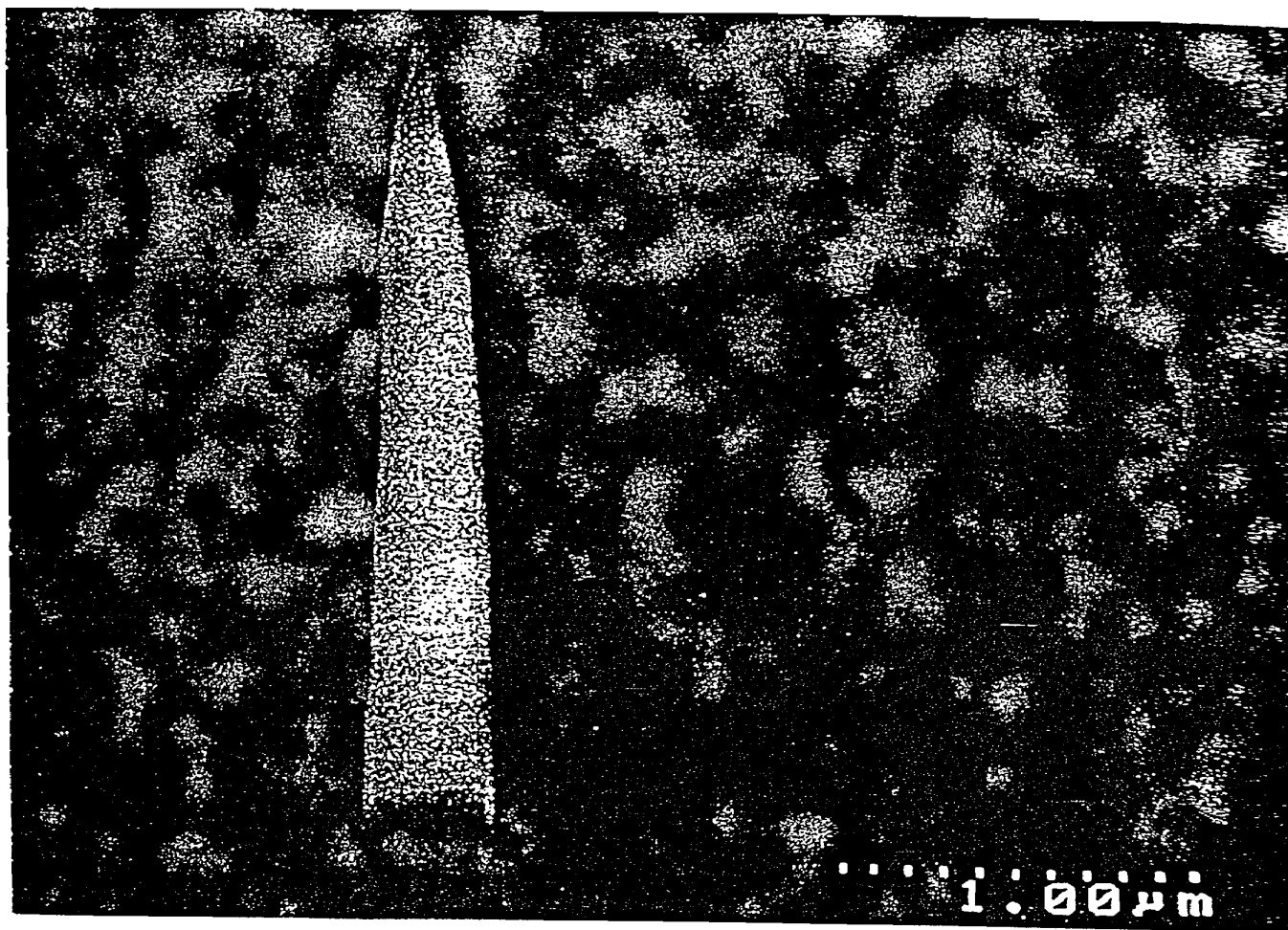


FIG. 19

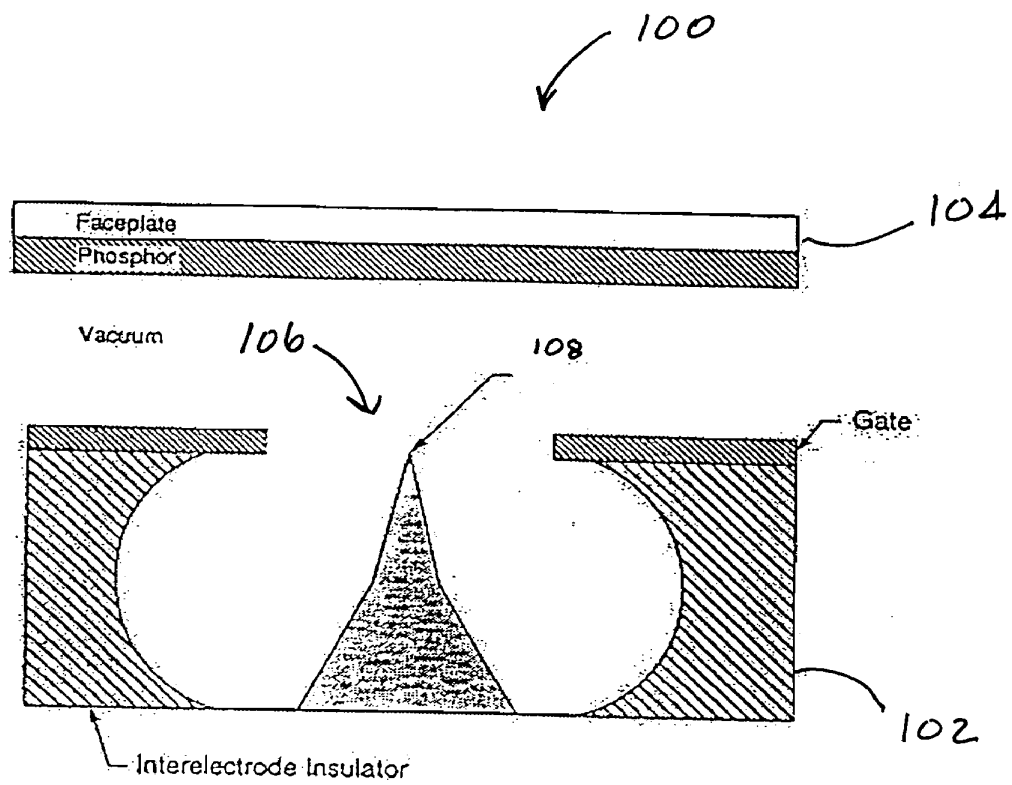


FIG. 20

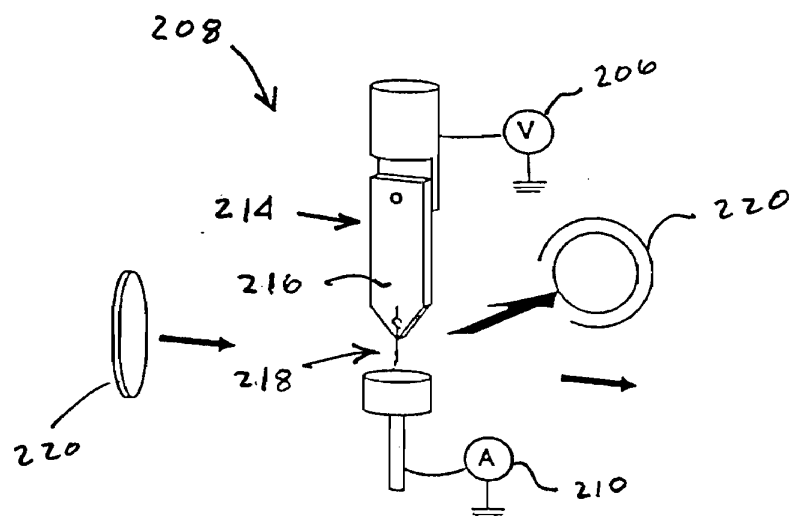


FIG. 21

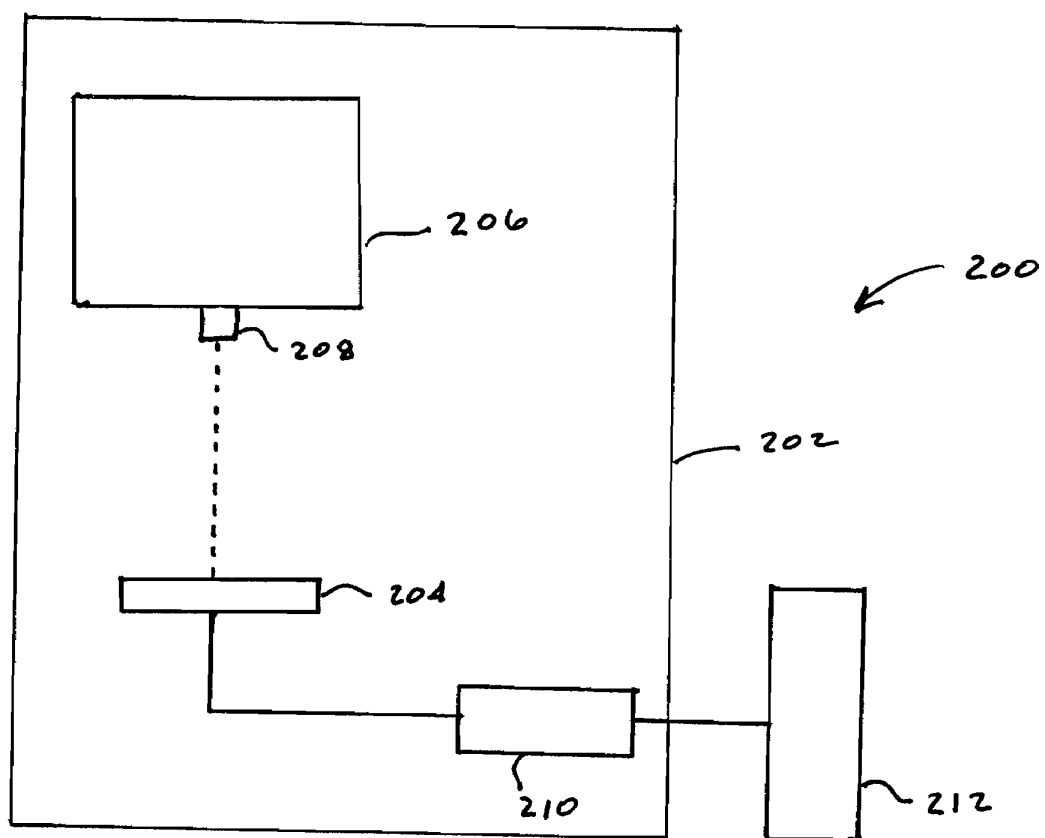


FIG. 22

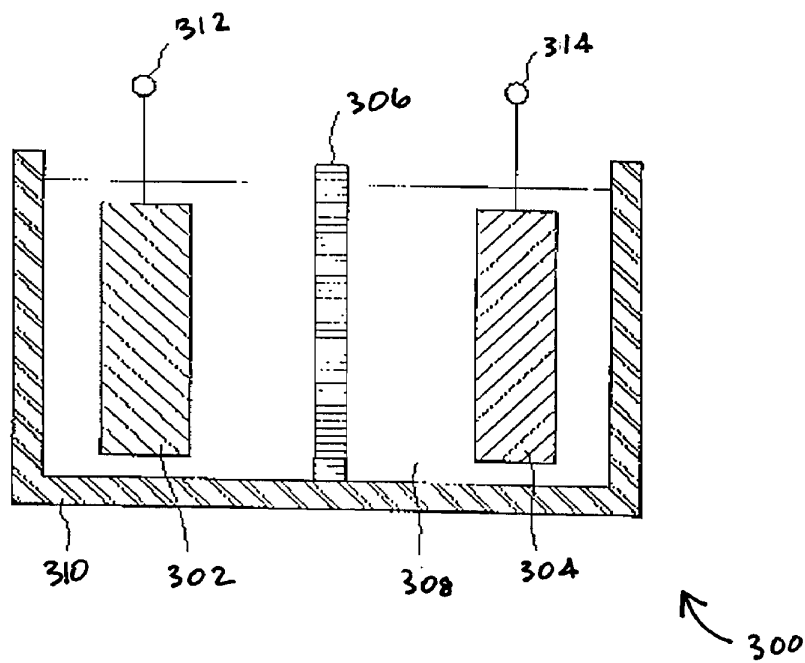


FIG. 23

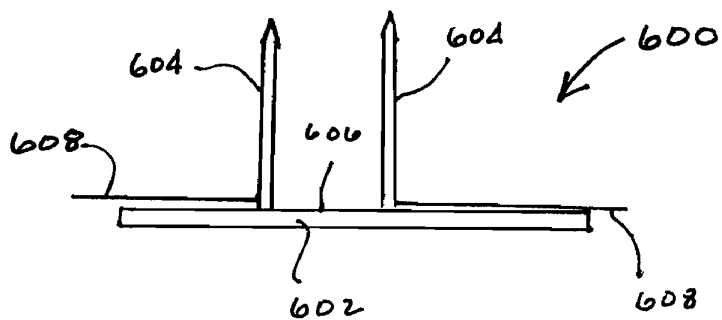


FIG. 26

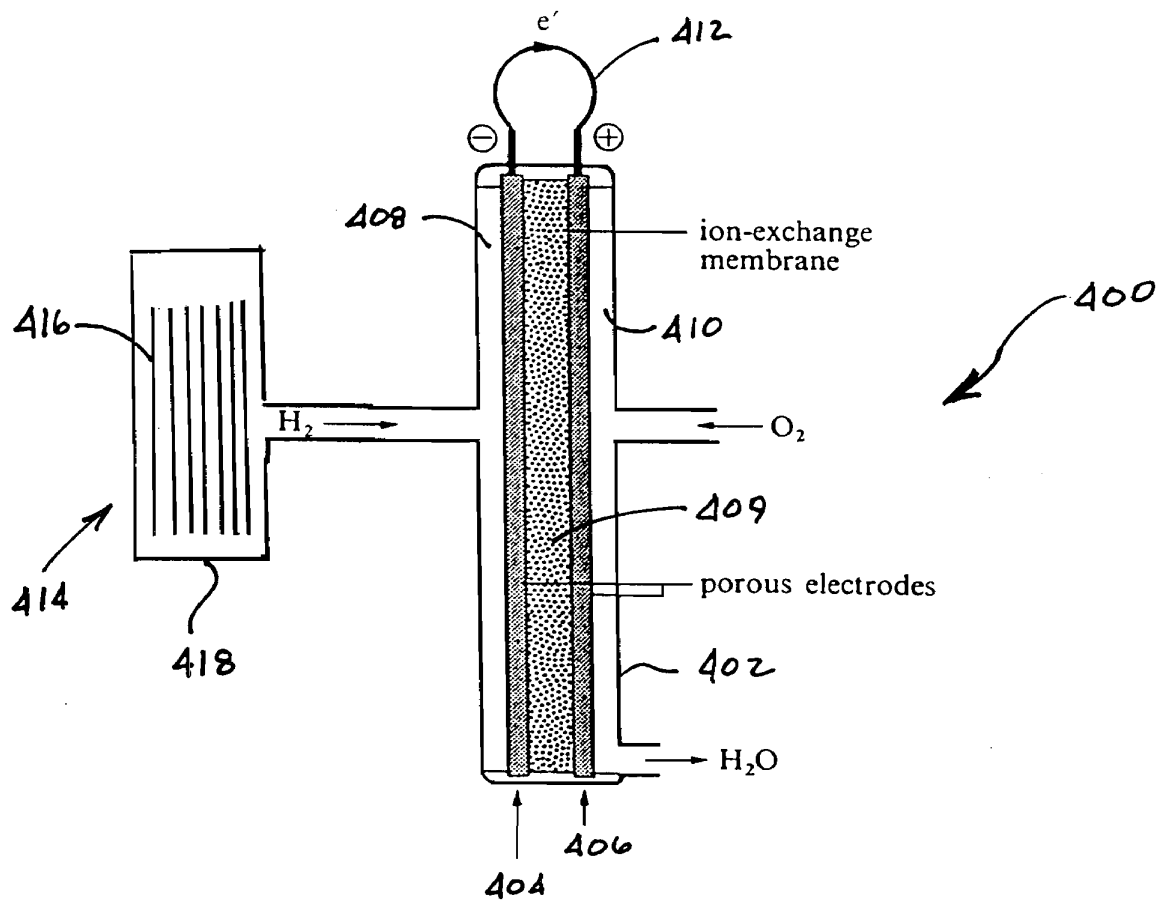


FIG. 24

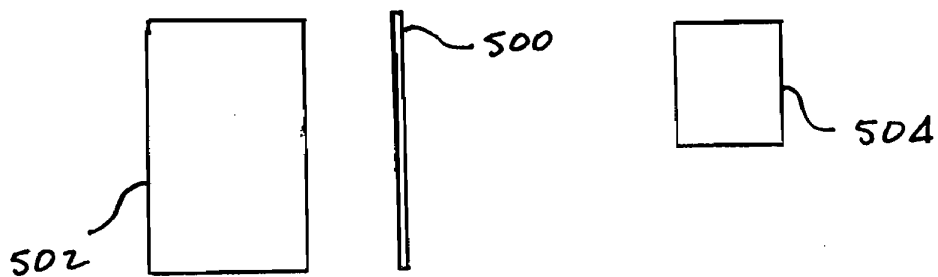


FIG. 25

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/13648

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : Please See Extra Sheet.

US CL : Please See Extra Sheet.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 423/445B, 447.1, 447.2, 447.3, 460; 427/216, 249, 562, 580, 590; 164/46; 429/231.8

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS, WEST

search terms: carbon nanotube, catalyst film, diameter, melting point

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|--------------------------------------------------------------------------------------------------------------------|-----------------------|
| A | US 5,346,683 A (GREEN et al.) 13 September 1994 (13-09-94), col. 2, lines 34-68, col. 3, lines 44-60 | 1-39 |
| A | US 5,648,056 A (TANAKA) 15 July 1997 (15-07-97), col. 1, lines 58-67, col. 2, lines 1-28, col. 5, lines 13-62 | 1-30 |
| A,E | US 5,916,642 A (CHANG) 29 June 1999 (29-06-99), col. 1, lines 58-67, col. 2, lines 1-20, col. 4, lines 13-50 | 6-77 |
| A,P | US 5,780,101 A (NOLAN et al.) 14 July 1998 (14-07-98), col. 4, lines 20-67, col. 5, lines 1-27, col. 9, lines 1-47 | 40-77 |



Further documents are listed in the continuation of Box C.



See patent family annex.

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| * Special categories of cited documents: | *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention |
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Date of the actual completion of the international search

16 AUGUST 1999

Date of mailing of the international search report

21 OCT 1999

Name and mailing address of the ISA/US
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Telephone No. (703) 308-0661

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/13648

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|--------------------------------------------------------------------------------------------------------------|-----------------------|
| A | US 5,726,524 A (DEBE) 10 March 1998 (10-03-98), col. 2, lines 39-67, col. 2, lines 5-65, col. 7, lines 13-67 | 1-67 |
| A | JP 407061803 A (NEC CORP) 07 March 1995 (07-03-95), abstract. | 1-12 |
| A | WO 009609246 A1 (ISIS INNOVATION) 28 March 1996 (28-03-96), abstract. | 12-69 |
| A | WO 009510481 A1 (DU PONT) 20 April 1995 (20-04-95), abstract. | 55-65 |
| A,P | JP 410265208 A (FINE CERAMICS CENTER) 06 October 1998 (06-10-98), abstract. | 1-39 |

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/13648

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☒
☐

The additional search fees were accompanied by the applicant's protest.
No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US99/13648

A. CLASSIFICATION OF SUBJECT MATTER:

IPC (6):

C01B 31/00, 31/02; D01F 9/12, 9/127; C23C 16/00, 16/26, 16/30; H01J 1/30; H01M 4/02

A. CLASSIFICATION OF SUBJECT MATTER:

US CL :

423/445B, 447.1, 447.2, 447.3, 460; 427/216, 249, 562, 580, 590; 164/46; 429/231.8

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING

This ISA found multiple inventions as follows:

This application contains claims directed to more than one species of the generic invention. These species are deemed to lack Unity of Invention because they are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for more than one species to be searched, the appropriate additional search fees must be paid. The species are as follows:

A. drawn to a first product comprising a substrate having carbon nanotubes at a density of more than 10^4 nanotubes/mm².

B. drawn to a second product comprising a substrate having carbon nanotubes at a density of less than 10^2 nanotubes/mm².

The claims are deemed to correspond to the species listed above in the following manner:

Specie A: 1-20, 78-86

Specie B: 21-37, 78-86

The following claims are generic: 38, 39, 40-77

The species listed above do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, the species lack the same or corresponding special technical features for the following reasons: The first and second products do not share the same structure, greater than 10^4 carbon nanotubes/mm² for the first product formed at a different plasma intensity from the second product having no more than 10^2 nanotube/mm².



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

| | | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| (51) International Patent Classification ⁵ : G21C X | A2 | (11) International Publication Number: WO 90/13129 (43) International Publication Date: 1 November 1990 (01.11.90) |
| (21) International Application Number: PCT/US90/01879 (22) International Filing Date: 6 April 1990 (06.04.90) (30) Priority data: 335,751 10 April 1989 (10.04.89) US 446,674 6 December 1989 (06.12.89) US (71) Applicant: MASSACHUSETTS INSTITUTE OF TECHNOLOGY [US/US]; 77 Massachusetts Avenue, Cambridge, MA 02139 (US). (72) Inventor: HAGELSTEIN, Peter, L. ; 31 Faulkner Hill Road, Acton, MA 01720 (US). (74) Agent: PASTERNAK, Sam; Choate, Hall & Stewart, Exchange Place, 53 State Street, Boston, MA 02109 (US). | | (81) Designated States: AT (European patent), BE (European patent), CA, CH (European patent), DE (European patent), DK (European patent), ES (European patent), FR (European patent), GB (European patent), IT (European patent), JP, KR, LU (European patent), NL (European patent), SE (European patent), SU. Published <i>Without international search report and to be republished upon receipt of that report.</i> |
| (54) Title: FUSION APPARATUS (57) Abstract Fusion apparatuses for coupling fusible material to a quantized mode to result in coherent fusion are provided. Method for optimization of reactor operation, control of the coherent fusion reaction and extraction of usable energy generated are provided. | | |

DESIGNATIONS OF "DE"

Until further notice, any designation of "DE" in any international application whose international filing date is prior to October 3, 1990, shall have effect in the territory of the Federal Republic of Germany with the exception of the territory of the former German Democratic Republic.

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FUSION APPARATUS

Background of the Invention

This application is a continuation-in-part of application USSN 335,751 filed April 10, 1989 by Peter L. Hagelstein entitled "Fusion Apparatus".

This invention relates to cold fusion apparatus.

Fleischmann and Pons have asserted that heat produced by electrolytically deuterium-loaded palladium rods results from near room temperature nuclear fusion (Fleischmann and Pons, *J. Electroanalytic Chemistry*, 261, 301 (1989); Petrasso, et al., *Nature* 339, 183 (1989); Fleischmann, et al., *Nature* 339, 667 (1989); Petrasso, et al., *Nature* 339, 667 (1989)).

"Cold fusion" effects have been reported in a number of electrolysis experiments (Jones, et al., *Nature* 339, 737 (1989); R. Huggins, presented at the Workshop on Cold Fusion Phenomena at Santa Fe, May 1989; Gozzi, et al., presented at the Workshop on Cold Fusion Phenomena at Santa Fe, May 1989; Srinivasan, et al., presented at the Workshop on Cold Fusion Phenomena at Santa Fe, May 1989; Bertin, et al., presented at the Workshop on Cold Fusion Phenomena at Santa Fe, May 1989; Wolf, et al., presented at the Workshop on Cold Fusion Phenomena at Santa Fe, May 1989) and in gas cells (De Ninno, et al., *Europhysics Letters* 9, 221 (1989); De Ninno, et al., presented at the Workshop on Cold Fusion Phenomena at Santa Fe, May 1989; experiments of Magini et al. and of Mazzone et al. of ENEA at Casaccia, discussed by Scaramuzzi at the Workshop on Cold Fusion Phenomena at Santa Fe, May 1989; Menlove, et al., presented at the Workshop on Cold Fusion Phenomena at Santa Fe, May 1989).

Other efforts to detect evidence of cold fusion have yielded negative results. (Gai, et al., *Nature* 340, 29 (1989); Hsuan, et al., presented at the Workshop on Cold Fusion Phenomena at Santa Fe, May 1989; Lewis and Barnes, presented at the Workshop on Cold Fusion Phenomena at Santa Fe, May 1989; Ziegler, et al., *Phys. Rev. Lett.*, 62, 2929 (1989); Albagli, et al., Workshop on Cold Fusion Proceedings to appear in *J. Fusion Energy* (1989)).

Efforts have been directed towards identifying the mechanism responsible for cold fusion effects (Lipson, et al., *Sov. Tech. Phys. Lett.*, 12, 551 (1989); Rafelski, et al., unpublished AZPH-TH/89-19 March 27, 1989, submitted to *Nature*; Garwin,

-2-

Nature 338, 616 (1989); Mayer, et al., presented at the Workshop on Cold Fusion Phenomena at Santa Fe, May 1989; Dickinson, et al., submitted to J. Mat. Res. (1989); Seitz, Nature 339, 185 (1989); Gajda, et al., presented at the Workshop on Cold Fusion Phenomena at Santa Fe, May 1989; Krapchev, unpublished; Cohen and Davies, Nature 338, 705; Richards, presented at the Workshop on Cold Fusion Phenomena at Santa Fe, May 1989; Sun and Tomanek, Phys. Rev. Lett., 63, 59 (1989); Koonin and Nauenberg, Nature, 339, 690 (1989) Tajima, et al., unpublished April 1989; Parmigiani and Sona, to appear in Il Nuovo Cimento (1989); Pharamwardana and Aers, submitted to Chem. Phys. Lett. (1989); Koonin, submitted to Phys. Rev. Lett., April 1989; Li, unpublished technical report, U. of Maryland, April 1989; Leggett and Baym, Phys. Rev. Lett, 63, 191 (1989); Leggett and Baym, Nature, 340, 45 (1989); Gryzinski, Nature, 338, 712 (1989); Johnson and Clougherty, to appear in Mod. Phys. Lett. B (1989); Guinan, et al., LLNL report 100881 (1989); Nazgamine, et al., presented at the Workshop on Cold Fusion Phenomena at Santa Fe, May 1989; Shibab-Eldin, et al., unpublished Lawrence Berkeley Laboratory, April 1989; Walling and Simons, unpublished U. of Utah, Chemistry Dept., April 1989; Irvine and Riley, Nature, 339, 515 (1968); W. Fowler, Nature, 339, 345 (1989); Danos, presented at the Workshop on Cold Fusion Phenomena at Santa Fe, May 1989).

Summary of the Invention

The coherent fusion apparatus of the invention includes a source of fusible material, for example deuterium, and a means for exciting that material to initiate and sustain coherent fusion. It further includes a means for monitoring the rate of the coherent fusion reaction such as a neutron or α -particle detector, and a means for extracting usable energy from the coherent fusion apparatus.

According to another aspect of the invention, fusible material is coupled to a quantized mode which may be a mechanical, electrical, magnetic, or composite mode so that this coupling is sufficiently strong to effect the onset of coherent fusion. In a preferred embodiment, fusible material is contained within an electrically conductive, radially symmetric containment vessel and coherent fusion is initiated through coupling to plasmon modes. In other embodiments, fusible material is contained within insulating vessels where coupling is accomplished by radially polarizing insulating crystals.

-3-

According to another aspect of the invention, the cosmic ray permeable fusion apparatus includes fusible material contained within an electrically conductive containment vessel provided with radially disposed rod-like projections electrically connected in series with an oscillator and in series or parallel with a computer-controlled variable load to extract energy from the coherent fusion process. An electrically excited coherent fusion apparatus may be coupled electrically to a load either in series or in parallel. This means of electric energy coupling may be tuned further by the insertion of a variable resistance element in these circuits.

In a preferred embodiment, the oscillator includes a variable quality factor (Q) resonator for acoustical excitation of fusible material, including hydrogen and deuterium in proportions adjusted for optimization of the coherent fusion rate. An α -particle source may also be provided to initiate coherent fusion. The vessel preferably consists of metal resistant to enhanced fission.

In another aspect of the invention, the fusion apparatus includes fusible material within an insulating containment vessel surrounded by radially disposed polarizable crystals and apparatus for extracting usable energy produced by the coherent fusion process.

In preferred embodiments of insulating containment vessel fusion apparatus, fusible material includes hydrogen and deuterium in proportions adjusted to optimize the coherent fusion rate. The coherent fusion process is stopped by selective introduction of a proton excess. Also, the vessel consists of low atomic number material, such as lithium hydride and is thin-walled. Usable energy can be extracted with a metal positron trap and heat built up within the apparatus may be removed by embedded, thermally conductive mesh. The vessel can be cosmic ray permeable and can include an α -particle source for fusion initiation.

All fusion apparatus can accommodate various radially symmetric geometry containment vessels including cylindrical, spherical, or toroidal geometries, use of gaseous, liquid, solid, or cryogenic fusible material including solids such as ice or metal hydrides and removal of by-products of the coherent fusion process such as tritium using a circulation loop. A selectively permeable membrane such as gold-coated palladium may be used to adjust hydrogen/deuterium fusible material ratios.

According to another aspect of the invention, a neutron or α -particle detector may be combined with a coherent fusion apparatus to monitor the fusion rate.

Coherent fusion reactors can also be used to drive lasers either by creating a large

-4-

potential difference needed to excite a gas discharge laser or by direct coupling to electronic transition lasers including gases such as N_2 , semiconductors such as GaAs or crystalline insulator laser hosts such as yttrium aluminium garnet (YAG).

A coherent fusion reactor may also be used to drive a vibrational transition laser or maser via direct or filtered energetic coupling.

The energy created in a coherent fusion apparatus can be used to promote a chemical reaction having a high activation barrier such as nitrate synthesis. This energy may also be utilized for transmutation of elements, generation of artificial isotopes, and processing of radioactive wastes to remove high atomic number radioactive isotopes.

Coherent deuterium fusion byproducts, 3He and neutrons, may be harnessed for useful purposes. The 3He may be contained for subsequent use in cryogenic studies and the neutrons may be utilized for neutron spectroscopy.

Brief Description of the Drawing

In the drawing:

Fig. 1a is a schematic cross section of a fusion apparatus;

Fig. 1b is a schematic illustration of a fusion apparatus coupled in parallel to a load;

Fig. 1c is a schematic illustration of a fusion apparatus coupled to a load in parallel with a variable resistance element;

Fig. 2a is a schematic sideview of a fusion apparatus; and

Fig. 2b is a schematic endview of a fusion apparatus;

Fig. 3 is a schematic illustration of a fusion reaction rate monitoring system consisting of a neutron detector positioned near a fusion apparatus;

Fig. 4 is a schematic illustration of a fusion apparatus used to excite a discharge laser;

Fig. 5 is a schematic illustration of a fusion apparatus used to excite a semiconductor laser;

Fig. 6 is a schematic illustration of a fusion apparatus used to excite electronic transitions in a laser wherein energetic coupling occurs directly between the fusion apparatus and the laser material;

Figs. 7a and 7b are schematic illustrations of fusion apparatus used for promoting a chemical reaction;

-5-

Figs. 8a and 8b are schematic illustrations of fusion apparatus used for transmutation of an element;

Fig. 9 is a schematic illustration of a fusion apparatus used to generate neutrons for spectroscopy;

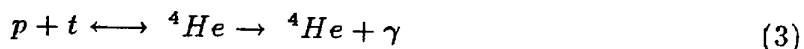
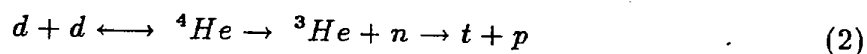
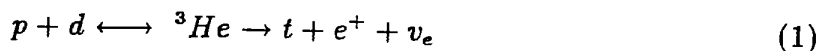
Fig. 10 is a schematic illustration of a fusion apparatus used to generate ${}^3\text{He}$;

Fig. 11 is a schematic illustration of a fusion apparatus excited by an ion beam; and

Fig. 12 is a schematic illustration of an amplifier which includes a fusion apparatus.

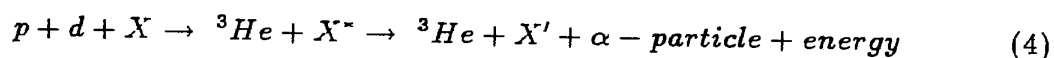
Description of the Preferred Embodiment

A simple model for coherent fusion in the presence of a lattice has been developed. The model suggests that the reactions



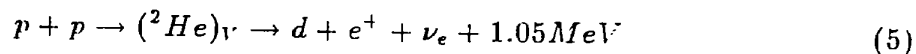
can occur coherently via an electric monopole (EO) interaction with a lattice. These fusion reactions are accelerated if the magnitude of the interaction matrix element exceeds the geometric mean of the phonon energy and the nuclear energy, neglecting damping.

An alternative, exotic, three-body proton-deuterium reaction can occur in the presence of a lattice of X nucleons which becomes excited to a state, X^* , before alpha decaying to X' according to the reaction:

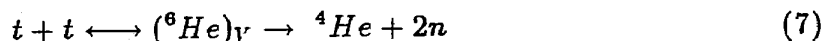
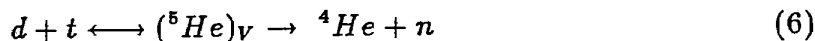


The excitation of palladium nuclei by 5.49 MeV leads to excited states for which fast alpha decay is a principal decay mode with neutron and proton emission energetically forbidden. The energies released are 3.38, 2.87, 2.59, 2.26, 1.64 and 1.06 MeV for palladium isotopes with A equal to 102, 104, 105, 106, 108, 110 respectively. This mechanism is not operative in titanium electrolysis cells.

A third class of reactions can proceed which produce virtual localized intermediate states according to the following reactions:



-6-



where $({}^n\text{He})_V$ indicates localized continuum states which have maximum overlap with the final state products. Virtual fusion reactions leading to stable ${}^3\text{He}$ and ${}^4\text{He}$ isotopes are exothermic; additionally, $d + d \longleftrightarrow {}^4\text{He}^*$ can be an exothermic virtual path. The remaining virtual fusion reactions are endothermic.

The incoherent branches can be either fast decays if mediated by the strong force or electromagnetic force, or slow decays if mediated by the weak force. In the case of fast decay channels, only a small fractional virtual population needs to be established to obtain an observable decay rate. For the beta decay paths, a very large virtual population is required to produce an observable effect. A formulation is developed which applies to both classes of reactions.

The overall scenario which we are attempting to develop works as follows: a mixture of protons and deuterons are introduced into a lattice, react virtually, and decay. The proton-proton path in this scenario produces heat, and the proton-deuterium path produces tritium. Since the beta decay is slow, a substantial virtual helium population is required to obtain observable levels of heat or tritium. The build-up of the virtual helium population takes time to occur (and may not occur in every experimental set-up). The $({}^2\text{He})_V$ decay to tritium takes about 200 sec. Thus, virtual $({}^2\text{He})_V$ levels can be in the vicinity of 10^{16} for a several-watt system. Such a picture is qualitatively consistent with the experimental report of Pons and Fleischmann.

Coherent acceleration of the fusion rate requires that coupling proceed to a single final state, and that the process be reversible, i.e., matrix elements for the reverse process be equal to those for the forward reaction. Coherent processes which occur in a phonon laser are distinguished from those in a conventional laser in that no conventional laser exhibits an interaction energy exceeding the transition energy. The fundamental constraint for the onset of coherent fusion is given by Equation 8 where H represents a static Hamiltonian, ω_n is the nuclear angular frequency, ω_p is the phonon angular frequency, and \hbar is Planck's constant/ 2π .

$$| \langle | H | \rangle | > > \sqrt{(\hbar\omega_n)(\hbar\omega_p)} \quad (8)$$

Energy produced from the interaction, fusion, of protons and deuterons couples to phonon modes. The rate of phonon generation when n nuclear fusions have occurred

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in the lattice is given by Equation 9

$$\gamma_p = \frac{4}{\pi} \frac{|\langle | H | \rangle|^2}{\hbar^2 \omega_n} \quad (9)$$

where γ_p is the phonon generation rate. Energy conservation requires that ω_n/ω_p phonons be generated for each fusion event, yielding an associated fusion rate, γ_f , given by Equation 10.

$$\gamma_f = \frac{4}{\pi} \frac{\omega_f}{\omega_n^2} \left| \frac{\langle | H | \rangle}{\hbar} \right|^2 \quad (10)$$

When large numbers of nuclear fusions occur in the lattice, the phonon generation rate, γ_p , is given by Equation 11

$$\gamma_p = \frac{4\sqrt{2}}{\pi} \omega_p \left| \frac{\langle | H | \rangle}{\hbar \omega_n} \right|^2 \quad (11)$$

which is smaller than the result obtained in Equation 9 by a factor $\sqrt{2}\omega_p/\omega_n$.

The model may be extended to describe the coupling of the nuclear energy generated to multiple phonon modes. Such coupling is assumed to be dominated by transitions in which only a single phonon is exchanged. Equations 12 and 13 may be used to develop estimates of coherent fusion effects in macroscopic systems. The total phonon generation rate, γ_p , may be interpreted physically as being equal to the sum of the rates of each mode acting independently. The associated total fusion rate is given by Equation 13.

$$\gamma_p = \sum_j \frac{4}{\pi} \frac{|\langle 0, m_j | H | l, m_j + 1 \rangle|^2}{\hbar^2 \omega_n} \quad (12)$$

$$\gamma_f = \frac{4}{\pi} \frac{\omega_j}{\omega_n} \frac{|\langle 0, m_j | H | l, m_j + 1 \rangle|^2}{\hbar^2 \omega_n} \quad (13)$$

The fusion rate for a given mode is essentially zero unless the interaction is strong enough such that the coherent fusion constraint (Equation 8) is satisfied. The constraint is a statement that the phonon generation rate must exceed the phonon frequency for strong coherence to be achieved. We may use this constraint to examine the threshold condition for the lowest mode of a macroscopic coherent fusion system.

A bar with a lowest mode of frequency 1 kHz (corresponding to a phonon energy of 4×10^{-12} eV) requires an interaction matrix element of 5×10^{-3} eV to reach threshold

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for the $p+d \rightarrow {}^3\text{He} + 5.5\text{MeV}$ reaction. The fusion rate under these conditions is quite small ($7 \times 10^{-15}\text{sec}^{-1}$).

In order to obtain a coherent fusion rate which is sufficiently large to be measurable, we require a much larger interaction matrix element as well as the participation of numerous phonon modes. As a crude approximation, we might imagine the interaction matrix element to be nearly constant over the low energy phonon spectrum. If this is assumed, then the fusion rate becomes

$$\gamma_f = \frac{4}{\pi} \left[\frac{|\langle |H| \rangle|}{\hbar\omega_n} \right]^2 \sum_j \omega_j \quad (14)$$

The number of modes which are available at a phonon frequency ω_j is on the order of $3V\omega_j^2 d\omega_j / (2\pi c)^3$, where c is the sound speed and V is the volume involved. The sum can be approximated by an integral if the number of modes is large, giving

$$\gamma_f = \frac{4}{\pi} \left[\frac{|\langle |H| \rangle|}{\hbar\omega_n} \right]^2 \frac{3V}{(2\pi c)^3} \int_0^{\omega_{\max}} \omega^3 d\omega \quad (15)$$

where ω_{\max} is the highest frequency for which phonon modes satisfy the coherence criterion:

$$\omega_{\max} = \frac{|\langle |H| \rangle|^2}{\hbar^2 \omega_n} \quad (16a)$$

$$\gamma_f = \frac{3V}{8\pi^4 c^3} \frac{\omega_{\max}^5}{\omega_n} \quad (16b)$$

The total fusion rate may be written in terms of the cutoff frequency in this crude model.

According to this model, the fusion rate is dominated by the highest frequency phonon modes which satisfy the coherence criterion. Moreover, an estimate of the frequency dependence of the phonon power generation spectrum is obtained. An estimate of what cutoff frequency would be required to generate a given power from a coherently fusing system can be made.

Denoting the power by $P = \gamma_f \hbar \omega_n$,

$$P = \frac{3\hbar V \omega_{\max}^5}{8\pi^4 c^3} \quad (17)$$

ω_{\max} is obtained.

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$$\omega_{max} = \left[\frac{8\pi^4 c^3 P}{3V\hbar} \right]^{1/5} \quad (18)$$

An estimate of the maximum phonon frequency for a system with the following parameters

$$P = 1 \text{ watt}$$

$$V = 1 \text{ cm}^3$$

$$c = 3 \times 10^5 \text{ cm/sec}$$

is about 1.5×10^9 Hz. The interaction matrix element must have a magnitude of about 6 eV under these conditions. In terms of the interaction matrix element, the generated power is

$$P = \frac{3V | \langle | H | \rangle |^{10}}{8\pi^4 c^3 \hbar^9 \omega n^5} \quad (19)$$

which shows explicitly the strong dependence of power generation on the interaction matrix element, assuming a constant interaction matrix element.

The interaction matrix element need only be constant over a small range for the total power estimate to remain valid.

The interaction matrix element required for computation of transition rates is given by equation 20.

$$\langle | H | \rangle = \langle \Phi_0(\Gamma) | H_I | \Phi_1(\Gamma') \rangle \quad (20)$$

where Γ and Γ' denote eigenstates which differ by one acoustical phonon mode. It is assumed that nuclear fusion energy couples predominantly into acoustical phonon modes because the interaction energy required to meet the criterion set forth in Equation 8 is several orders of magnitude lower for acoustical than for optical phonons. However, optical phonon modes may be involved in this energy coupling since optical phonons are associated with relative nuclear motion which enhances tunneling probabilities moreso than lattice motion associated with acoustical phonon modes.

The dominant coupling between the nuclear fusion energy and lattice will proceed through the electromagnetic monopole E0 interaction which is stronger than an electromagnetic dipole E2 interaction because it can extend over a long range and involves an overlap integral rather than a quadrupole matrix element.

The E0 term is found to be

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$$\frac{e^2}{r_{>}} \rightarrow \frac{2e^2}{\pi} I_0(\omega, r_i, r_j) = \frac{e^2}{\pi} \frac{1}{\omega r_i r_j} \left\{ \ln \frac{r_j + r_i}{r_j - r_i} + g[\omega(r_j + r_i)] - g[\omega(r_j - r_i)] \right\} \quad (21)$$

where

$$g(z) = -Ci(z)\cos z - si(z)\sin z \quad (22)$$

This more sophisticated version of the E0 operator behaves like $e^2/r_{>}$ over distances small compared to the wavelength of an exchanged photon, and goes as $2e^2/\omega\pi r_{>}^2$ in the limit that $r_{>}$ is much greater than the wavelength.

The wavelength of an exchanged photon can easily be on the order of the rod size or larger for coupling to acoustical phonons. Conversely, the interaction region is smaller in the case of coupling to optical phonons, since the photon wavelength becomes significantly smaller than the rod dimensions.

An order of magnitude estimate for the interaction matrix element may be obtained using equation 23.

$$\langle 0, m_K | H | 1, m_K + 1 \rangle \approx 4I_H \frac{a_0^2}{R^2} N_C N_{pd} \sqrt{\frac{m_e}{M}} \sqrt{\frac{I_H E_K}{(\hbar\omega_K)^2 N_L}} \langle \phi_{pd} | \phi^3 He \rangle \quad (23)$$

where a_0 is the Bohr radius, I_H is 13.6eV, N_C is the number of excess charges at a mean distance R , N_L is the number of nucleons in the lattice, N_{pd} is the number of proton/deuteron pairs which are S-wave with respect to each other and where E_K is the energy in phonon mode K .

A system can be designed to optimize this interaction matrix element and obtain results which correlate with physical observables. For a centimeter scale system, with macroscopic energy applied to the lowest frequency mode in the presence of a very strong electric field, an interaction matrix element on the order of 10^{-7}eV can be obtained for the reaction given by Equation 1. This interaction matrix element can be substantially larger for a meter scale system, and may give rise to a measurable effect.

According to the foregoing analysis for exothermic p-d and d-d reactions (Equations 1 and 2), a reaction given by Equation 1 should only yield measurable effects for a meter scale system and is too weak to play a major role in the small scale laboratory systems characterized to date.

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The model developed so far may be extended to describe the reaction of Equation 5. The larger tunneling probability of the two proton system, due to its smaller reduced mass by comparison with p-d or d-d systems, makes coherent fusion effects observable in centimeter-scale systems.

The fusion reaction product of proton-proton fusion is not a stable particle. Proton-proton fusion reactions are endothermic, and absorb rather than radiate phonons. In a coherent fusion model, two-proton fusion is predicted to occur, although not in the same way that conventional fusion occurs. The fusion reaction products would be present virtually, and would be undetectable in the absence of any additional reaction pathways. A beta decay mode is hypothesized for the virtual two-proton fusion reaction product. Also hypothesized is an ultimate product, deuterium, for the proposed two-step fusion/beta path, $d + e^+ + \nu_e$.

The reaction rate for this channel can be estimated as the product of the virtual $(^2\text{He})_v$ probability and the associated beta decay rate. If the coupled lattice/nuclear system satisfies a coherence criterion for a low energy acoustical phonon mode, that mode will drive virtual $(^2\text{He})_v$ production at a finite and calculable rate. As the virtual fusion products build up within the lattice, beta decay takes place more frequently. An equilibrium is established when the total rate of virtual helium creation through coherent interactions with the lattice becomes equal to the rate at which it is destroyed by beta decay. As a result, in equilibrium, we may estimate the two-step fusion/beta reaction rate from the virtual fusion rate alone using the model already developed.

These results were derived for exothermic proton-deuteron and deuteron-deuteron reactions. In the case of endothermic virtual proton-proton fusion, phonons are destroyed rather than created; nonetheless, the coherent model applies. These rates describe the production of virtual fusion product state, and some exothermic incoherent channel is required to obtain real, i.e., irreversible, reaction products in the presence of relatively constant lattice conditions.

The interaction matrix element for proton-proton reactions, H_K , may be evaluated from equation 24

$$H_K = \int E_V(r) \cdot m_K(r) d^3r \quad (24)$$

where $E_V(r)$ is the virtual electric field, and $m_K(r)$ is the monopole density.

For a system of H_2 of density n_{pp}^0 placed between two very long cylindrical ca-

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capacitor plates of length L and radii r_1 and r_2 , assume that when fully charged, the capacitor develops a uniform surface charge σ_0 on the interior of the outer cylinder and a matching surface charge $-R_2\sigma_0/R_1$ on the surface of the inner cylinder.

Under these conditions, the virtual electric field is

$$E_V(r) = \hat{i}_r 2\pi \epsilon n_{pp}^0 P_0(r - \frac{R_1}{r}) \quad (25)$$

The monopole density is

$$m_K(r) = \sigma_0 \delta(r - R_2) u_K(r) \langle m_K | q_K | m_K + 1 \rangle \quad (26)$$

With these definitions, the interaction matrix element of Equation 27 can be evaluated

$$H_K = 8\pi^2 \epsilon n_{pp}^0 P_0(R_2^2 - R_1^2) L \sigma_0 u_r(R_2) \langle m_K | q_K | m_K + 1 \rangle \quad (27)$$

where $\epsilon = 1$. By symmetry, coupling occurs only with cylindrical \hat{i}_r -polarized modes, and of these modes only the longitudinal modes survive the spatial integration defining the continuum version of the interaction matrix element.

Assume that the total number of H_2 molecules, $N_{pp} = (R_2^2 - R_1^2) L n_{pp}^0$ is 10^{25} , and that all H_2 molecules are in the ground state, i.e., there is no vibrational or rotational excitation, then $P_0 \simeq 4 \times 10^{-32}$ is computed numerically. For a surface charge density of 10^{11} charges/cm², corresponding to an applied electric field strength of 1.8 and 10^5 Volts/cm, and outer cylinder vibrating strongly in radial compressional modes of surface amplitude 0.1 cm, an interaction matrix element on the order of 0.014 eV is obtained.

This example demonstrates that the interaction matrix element can be substantial under laboratory conditions. The beta decay rate, γ_β , can be estimated through the Gamow-Teller interaction for $(^2He)_V$ as $\gamma_\beta = 4 \times 10^{-3} \text{ sec}^{-1}$. In equilibrium, the total number of virtual localized proton-proton pairs can be inferred according to Equation 28

$$N_{(^2He)_V} = \frac{\gamma_f}{\gamma_\beta} \quad (28)$$

It follows that some time will be required for the population of virtual pairs to build up to the equilibrium value. This time would be of the order of the beta decay time were the system linear. If the mode amplitudes themselves build up through

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some other mechanism, i.e. through p+d coherent fusion, then this build-up time will be longer.

The mechanism described here also applies to the two step reaction $p + d \leftrightarrow {}^3\text{He} \rightarrow t + e^+ + \nu_e$. The coherent fusion reaction, $p + d \leftrightarrow {}^3\text{He}$, has been discussed previously, and ${}^3\text{He}$, will be present in virtual states during the course of sustained coherent fusion reactions. The interaction matrix element for the fusion process will be smaller than for two-proton coherent fusion by the ratio of tunneling factors on a per pair basis; this ratio is on the order of 10^{-4} for HD versus H_2 .

A related two-step reaction which can produce neutrons is the $d + d \leftrightarrow {}^4\text{He} \rightarrow {}^3\text{He} + n$ reaction. Coherent fusion of deuterons would lead to virtual ${}^4\text{He}$, which would have a fast allowed neutron-producing decay channel.

A model for coherent fusion in which the nuclear energy is released into the acoustical phonon modes of a lattice has been developed. Coupling of the nuclear energy to the phonons can occur rapidly if the interaction couples energy one phonon at a time and if the interaction matrix element exceeds the geometric mean of the phonon energy and nuclear energy as given by Equation 3. It is important to note that this analysis applies to any type of quantized modes, mechanical, electrical, magnetic or composite as long as the coupling is strong enough to satisfy the coherence criterion of Equation 8. The coherent reactions given by Equations 1-3 can proceed through electromagnetic E0 coupling of the nucleons to excess charge in the lattice as governed by the interaction matrix element which can be calculated as previously outlined.

The fusion apparatus of this invention will now be discussed with reference to the drawing.

In Fig. 1, fusion apparatus 10 consists of containment vessel 12 for fusible material, connected electrically in series to oscillator 14 for coupling to plasmon modes and to computer-controlled variable load 16 for extracting usable energy generated by the coherent fusion process.

Vessel 12, constructed of electrically conductive material, is fabricated in a cylindrical, radially symmetric geometry and is provided with external, radially disposed, rod-like projections 18 for coupling to fusible material 20. Material 20 may include both hydrogen and deuterium with an H_2 concentration of 10^{29} atoms. In a preferred embodiment, this mixture is adjusted at a ratio 10^8 deuterons/protons to obtain p-p coupling and avoid more likely p-d coupling. Material 20 can be in the gas, liquid, or solid phase or can be maintained at a cryogenic temperature to reduce proton-

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deuteron exchange. Solid material 20 can include ice or a metal hydride. Material 20 can be replenished by introduction of protons into vessel 12 from a proton source not shown. A selectively permeable membrane not shown consists of gold-coated palladium and adjusts the hydrogen-deuterium mixture. Vessel 20 may be provided with a circulation loop not shown for removal of by-products of the coherent fusion process such as tritium which accumulate during operation of apparatus 10.

Rod-like projections 18 which may be positioned on isopotential curves are electrically connected in series to oscillator 14, which can include a variable quality factor (Q) resonator not shown. Tuning such a resonator such that a low Q is selected makes the circuit "lossy" and the oscillator then functions as if it were a load, acting eventually to shut off apparatus 10. Projections 18 should be approximately one meter long for an approximately 20 meter long reactor.

One or more projections 18 can be individually coupled to high quality factor (Q) resonators, since coupling between modes is independent. In general, fusion initiation is easier for larger reactors where larger modes, having greater gain may be established.

Usable energy is extracted from fusion apparatus 10 using a computer-controlled variable load 16 which may include a switch to open electrical circuit 22, thus stopping the coherent fusion process. Load 16 may be connected to apparatus 10 in series as shown in Fig. 1a, in parallel as shown in Fig. 1b, or in parallel with variable resistor 17 as shown in Fig. 1c.

Figs. 2a and 2b show fusion apparatus 30 wherein fusible material 32 is contained within insulating containment vessel 34 and insulating crystals 36 are disposed radially in close proximity external to vessel 34 and fusible material 32. A microwave generator not shown can be used to polarize the insulating crystals 36 and establish coupling between fusible material 32 and plasmon modes according to a method well-known to one skilled in the art. Metal positron trap 38 surrounds material 32 and crystals 36 (Fig. 2b). Heat is generated as positrons become trapped. Metals are suitable positron traps. Heat generated within the interior of apparatus 30 may be removed by thermally conductive mesh not shown embedded within vessel 34.

Fig. 3 shows an apparatus for monitoring the reaction rate of a fusion reaction. Neutron detector 40 whose fabrication is well known in the art is positioned in close proximity to coherent fusion apparatus 42. Arrow 44 represents the flux of neutrons emitted as a result of the fusion process occurring within the reactor.

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Neutron detector 40 can be replaced by an α -particle detector not shown whose fabrication is also well-known in the art. Since enhanced α -decay results from coherent fusion induced nuclear polarization, α -particle emission is a sensitive indicator of the coherent fusion rate.

The potential differences created by positron and annihilation γ -rays can be used to excite gas discharge laser 50 shown in Fig. 4. Current source 52 assists in fusion initiation in fusion apparatus 54 connected in parallel to current source 52 and to variable resistance element 56. Fusion apparatus 54 is also connected in parallel with electrodes 58 which are enclosed within chamber 60. Chamber 60 contains gas lasing medium 62 and a laser cavity is established in vessel 60 by installation of mirrors 63. Ground 64 is provided for laser 50 and arrow 66 indicates the direction of current flow in the circuit.

Energetic electron positron generation from a coherent fusion reactor can be electrically coupled to semiconductor laser 70 shown in Fig. 5. Current source 72 is used to assist in coherent fusion initiation in fusion apparatuses 74. Apparatuses 74 are electrically coupled to semiconductor 76. Coupling between the coherent fusion reactors and semiconductor 76 can promote a large concentration of electrons to the conduction band of the semiconductor, while a large concentration of holes are simultaneously created in the valence band. This way, the condition of population inversion required for laser operation is established.

A laser cavity is created with mirrors 78. A suitable material for semiconductor 76 should have a direct band gap and gallium arsenide, or one of its related III-V compound alloys such as $Al_xGa_{1-x}As_ySb_{1-y}$ and $Ga_zIn_{1-z}As_yP_{1-y}$. The alloy composition selected for semiconductor 76 can be chosen on the basis of the lasing wavelength required. Ground 80 is provided for laser 70 circuit and the direction of current flow is indicated by arrow 82.

The energy of the coherent fusion process can also be used to drive a vibrational laser or maser. One embodiment for a coherent fusion driven laser or maser 90 is shown in Fig. 6. Coherent fusion reactor 92 is coupled directly to laser gas 96. Energetic positron and annihilation γ -radiation can drive $n=2$ or higher states in virtually any molecule including CO_2 , N_2 , HF , CO , and O_2 . The only molecules excluded are H_2 , D_2 and HD . An optical cavity is configured using mirrors 98. Any cavity configuration can generate efficient lasing in the 0.01-0.1eV range. Efficient microwave amplifiers can also be constructed.

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Energetic positrons produced by a coherent fusion reaction can also be utilized to promote chemical reactions, for example, nitrate synthesis. Nitrogen containing compounds such as NO and ND_3 can be produced. ND_3 can be converted to NH_3 by isotopic exchange.

Reaction vessel 100 appropriate for such a synthesis is shown in Fig. 7a. Within container 102 electrodes 104 composed of a fusion host material are immersed in a liquid medium 106 such as D_2O . Inlet 108 in container 102 permits introduction of a reactant gas such as nitrogen, N_2 . The direction of gas flow is indicated by arrow 110. The coherent fusion reaction is excited by an external excitation apparatus such as a battery now shown. An insulating vessel cover 114 and electrical ground 116 are provided.

Energetic positrons promote chemical reactions near the coherent fusion reactor surface. Thus, as shown in Fig. 7b, fusion apparatus 120 is positioned in close proximity to reactants 122 which can be liquid or gas. Most reactions are expected to occur at reactor surface 124 which may be a selectively permeable gold-coated palladium membrane. Using such a configuration, a desired compound may be synthesized directly without production of a deuterated intermediate product.

It is also possible to utilize energy from a coherent fusion reaction for transmutation of elements and production of isotopes not found in nature. An apparatus for transmutation and isotope production 130 is shown in Fig. 8a. Electrodes 132 composed of a fusion host material are immersed in medium 134 containing the element to undergo transmutation in container 136. The coherent fusion reaction is initiated by an external battery, not shown. Insulating cover 138 and ground 140 are provided. Using this apparatus, high atomic number radioactive isotopes may be reduced to stable isotopes through enhanced α -decay.

Transmutation of elements can be achieved by coupling fusion apparatus 150 directly to material to be transmuted 152 such as high atomic number radioactive isotopes. Selectively permeable membrane 154 which can be gold-coated palladium separates apparatus 150 from material 152.

The neutrons produced as a result of the reaction given by equation 2 can be used in neutron spectroscopy. Fig. 9 shows a coherent fusion reactor driven neutron spectrometer 160. Coherent fusion reactor 162 produces neutrons which are transferred from reactor 162 through conduit 164. Neutrons are monitored with a first monitor counter 166 and intensity may be controlled using auxiliary gate 168. A

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particular neutron energy bandwidth is selected using monochromator crystal 170. Monochromatic neutrons emitted from crystal 170 are measured with second monitor counter 172 before interacting with specimen 174. Neutrons which have interacted with specimen 174 are analyzed by analyzer crystal 176 and $^{10}\text{BF}_3$ counter 178. Crystal indexing unit 180 is used for orientation of specimen 174. Spectrometer 160 is thoroughly shielded with rotatable shielding 182 and additional yoke and shielding 184 to contain stray neutron radiation.

As shown in Fig. 10, a lattice 190 including fusible material which can be a mixture of hydrogen and deuterium is bombarded by an ion beam from generator 192 to initiate coherent fusion. Energy output is represented by arrow 194.

Fig. 12 shows an amplifier 200 which consists of fusion apparatus 202 and metal plate 204 contained within a vacuum. Energetic positrons collect on surface 206 which can be a selectively permeable gold-coated palladium membrane thus establishing a potential difference of approximately MeV between surface 206 and metal plate 204 which may be positioned from surface 206. Energy may be obtained directly when positrons cross evacuated gap 208.

The reaction given by Equation 1 results in the production of ^3He , a material useful for low temperature cryogenic studies. Fig. 11 illustrates one embodiment of an apparatus for collection of ^3He collection system 210, ^3He 212 produced by coherent fusion reactor 216 is collected in gas impermeable vessel 218.

Abstract

We propose that energy from nuclear fusion reactions can be coupled to a macroscopic system coherently (in the laser sense) through electromagnetic interaction of low energy photons. We report progress on the formulation of a theory for two-step reactions in which virtual fusion is followed by exothermic incoherent decay. A new type of reaction in which incoherent electron capture is followed by coherent fusion is described.

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I. Introduction

The claim of Pons and Fleischmann of the observation of fusion in an electrolysis cell^[1] has been met with extreme skepticism by the scientific community^[2]. The experiment has been exceptionally difficult to reproduce,^[3-7] and no credible theoretical explanation of any low temperature fusion mechanism which can account for the claimed observations has been given to date.

Based on the reports of fusion at room temperature, we have been seeking new mechanisms in which fusion is enhanced in the presence of a lattice. We have proposed a coherent fusion model for $p + d \rightarrow {}^3\text{He}$ fusion, with the nuclear energy being radiated into the lattice phonon field, one phonon at a time through electromagnetic interaction with the lattice.^[8]

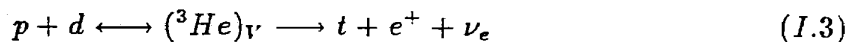
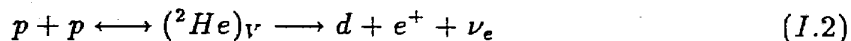
In this work we report progress on the formulation of a model with which we may analyze the reaction dynamics of a class of coherent fusion reactions.

The basic premise of the theory is that off-resonant coupling between two fusing nucleons and a macroscopic system can occur through the electromagnetic interaction. An example of such a virtual fusion reaction is

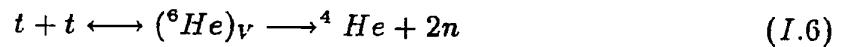
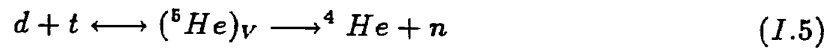
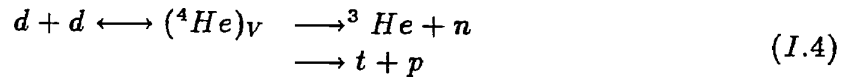


For example, a proton and a deuteron can fuse conventionally to ${}^3\text{He}$ following the emission of a 5.5 MeV gamma. If instead a low energy photon is exchanged, ${}^3\text{He}$ is still created, but only in a virtual sense. Our discussion applies to reactions involving other isotopes as well, but due to the low reduced mass and low Z of the hydrogen isotopes, we anticipate that non-hydrogenic reactions involving charged nucleons will be weaker.

In the absence of any further reaction pathways, the virtual fusion products are essentially nonobservable and hence of little interest. But exothermic incoherent reaction pathways exist for most of the virtual fusion products. The two-step reactions which proceed through virtual intermediate states and are of interest here include



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In these reactions, the notation $(^nHe)_v$ denotes a virtual intermediate state. In the case of 3He and 4He ground state spatial orbitals, the time dependence will correspond to a state with an energy equal to the initial state energy minus the energy of the exchanged photon. These virtual fusion reactions are exothermic; additionally $d + d \longleftrightarrow ^4He^*$ would be an exothermic virtual reaction. The other intermediate states in this scenario are localized continuum states with maximum overlap with the decay products. These virtual reactions are endothermic. A schematic of the proton-deuteron reaction is shown in Figure 1.

The incoherent branches can be either fast decays if mediated by the strong force or electromagnetic force, or else slow decays if mediated by the weak force. In the case of fast decay channels, only a small fractional virtual population needs to be established to obtain an observable decay rate. For the beta decay paths, a very large virtual population is required to produce an observable effect. The formulation which we are developing applies to both classes of reactions.

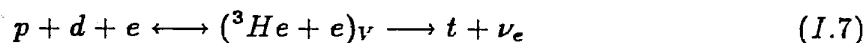
The overall scenario which we have considered works as follows: a mixture of protons and deuterons are introduced into a lattice, react virtually, and decay. The proton-proton path in this scenario produces heat, and the proton-deuterium path produces tritium. Since the beta decay is slow, a substantial virtual helium population is required to obtain observable levels of heat or tritium. The build-up of the virtual helium population would take time to occur. We estimate the $(^2He)_v$ decay into deuterium to take about 200 sec (from ft-theory, of Ref. 9 and 10) and therefore we require virtual $(^2He)_v$ levels to be in the vicinity of 10^{16} for a several-watt system for this scenario.

In this work we have begun an analysis of this approach. A rather immediate result of the analysis is that while the coherent fusion effects are undoubtedly real, they are clearly very small under normal conditions. The tunneling into the nuclear states is

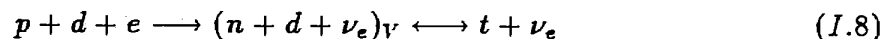
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so weak that even collective interactions have difficulty producing a net observable effect.

The original scenario seemed to be qualitatively consistent with the experimental report of Pons and Fleischmann when we began our study. We have recently learned that the measured gamma spectrum is inconsistent with positron production at levels which accompany such a picture (K. Wolf, Texas A& M, private communication). As a result, we have begun to consider the extension of the coherent model to other types of reactions. For example, the beta decay involving positron emission could be replaced with electron capture by the virtual fusion product. For example,



Alternatively, the electron capture could occur first (leading to a virtual intermediate), and the fusion reaction would follow. For example,



This type of reaction has the advantage that there is no coulomb barrier to inhibit tunneling between the fusing nucleons. Further discussion of alternate reactions of this type is given in the last section.

Our paper is organized as follows: In section II we consider nuclear populations and polarization in the presence of a semiclassical interaction hamiltonian. The model is found to be very close to semiclassical models used in laser physics. In section III we diagonalize the semiclassical hamiltonian, using a transformation which will help in analyzing more complicated systems. We next consider a quantum phonon model coupled to a classical source, and find a criterion for net phonon gain. In section V, we consider a coupled lattice nuclear system (section VI), and find that the system is approximately diagonalized with our rotation of section III. We next investigate a driven system, and find that in the dressed state picture external perturbations can create fusions through a second order interaction. In section VII we extend our analysis to include nonlinearities and strong driving terms.

II. Semiclassical Field Model

We first consider a system of pairs of hydrogen isotopes interacting with a semiclassical potential. The hamiltonian for the system is taken to be

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$$\widehat{H} = \widehat{H}_N + \widehat{H}_I \quad (II.1)$$

We will adopt a second quantization formulation (see Appendix A) for the nuclear transitions, and take \widehat{H}_N to be

$$\widehat{H}_N = \frac{1}{2} \hbar \omega_n \sum_{kl} b_{kl}^\dagger b_{kl} - b_{kl} b_{kl}^\dagger \quad (II.2)$$

where the creation and annihilation operators b^\dagger and b are fermionic, and satisfy anticommutation relations

$$b_{kl}^\dagger b_{kl} + b_{kl} b_{kl}^\dagger = 1 \quad (II.3)$$

The summation is over nucleon pairs with indices k and l . The interaction matrix element can be written in the form

$$\widehat{H}_I = \frac{\partial H_I}{\partial b} \sum_{kl} b_{kl}^\dagger + b_{kl} \quad (II.4)$$

In the case of M1 interaction, $\widehat{H}_I = \widehat{\mu} \cdot \widehat{\mathbf{B}}$ where the magnetic dipole operator $\widehat{\mu}$ is

$$\widehat{\mu} = \mu \sum_{kl} b_{kl}^\dagger + b_{kl} \quad (II.5)$$

where the single-pair magnetic dipole moment is

$$\mu = \frac{e\hbar}{2Mc} \langle \phi_u | \sum_i g_i^l \mathbf{l}_i + g_i^s \mathbf{s}_i | \phi_f \rangle \quad (II.6)$$

and where the subscripts u and f denote unfused and fused states.

We assume for simplicity that $\frac{\partial H_I}{\partial b}$ is independent of space in the vicinity of the fusing nucleons, although it can be time-dependent. The algebra for this hamiltonian is simplified if the hamiltonian is cast in terms of many-particle operators. We define three many-particle operators to be

$$\widehat{\Sigma}_x = \sum_{kl} b_{kl}^\dagger + b_{kl} \quad (II.7)$$

$$\widehat{\Sigma}_y = \frac{1}{i} \sum_{kl} b_{kl}^\dagger - b_{kl} \quad (II.8)$$

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$$\hat{\Sigma}_z = \sum_{kl} b_{kl}^\dagger b_{kl} - b_{kl} b_{kl}^\dagger \quad (II.9)$$

These operators obey commutation relations similar to many-particle spin operators. In terms of these operators, the hamiltonian is

$$\hat{H} = \frac{1}{2} \hbar \omega_n \hat{\Sigma}_z + \frac{\partial H_I}{\partial b} \hat{\Sigma}_x \quad (II.10)$$

The time-evolution equations for the expectation values of these operators can be found through

$$\frac{d}{dt} \langle \hat{\Sigma}_i \rangle = \frac{1}{i\hbar} \langle [\hat{\Sigma}_i, \hat{H}] \rangle \quad (II.11)$$

The resulting evolution equations are

$$\frac{d}{dt} \langle \hat{\Sigma}_x \rangle = -\omega_n \langle \hat{\Sigma}_y \rangle \quad (II.12)$$

$$\frac{d}{dt} \langle \hat{\Sigma}_y \rangle = \omega_n \langle \hat{\Sigma}_x \rangle - \frac{2}{\hbar} \frac{\partial H_I}{\partial b} \langle \hat{\Sigma}_z \rangle \quad (II.13)$$

$$\frac{d}{dt} \langle \hat{\Sigma}_z \rangle = \frac{2}{\hbar} \frac{\partial H_I}{\partial b} \langle \hat{\Sigma}_y \rangle \quad (II.14)$$

We shall define the population inversion and polarization averages to be

$$N^* = \langle \hat{\Sigma}_z \rangle \quad (II.15)$$

$$M = \langle \hat{\Sigma}_y \rangle \quad (II.16)$$

$$O = \langle \hat{\Sigma}_x \rangle \quad (II.17)$$

Our definition for the population inversion N^* follows the definition from laser physics, and is given by the number of upper state "systems" minus lower state "systems". For example, the $p + d \longleftrightarrow ({}^3\text{He})_V$ reaction is exothermic. The population inversion is given by the number of pd pairs minus the number of $({}^3\text{He})_V$ nuclei. In the case of $p + p \longleftrightarrow ({}^2\text{He})_V$, which is endothermic, N^* is the population of $({}^2\text{He})_V$ minus the number of pp pairs. The energy $\hbar\omega_n$ is the positive energy difference between the upper and lower states.

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Following the development which is often used in laser physics, we add relaxation terms accounting for the destruction of inversion and polarization.

$$\frac{d}{dt}N^* + \frac{N^* - N_0^*}{T_1} = \frac{2}{\hbar} \frac{\partial H_I}{\partial b} M \quad (II.18)$$

$$\frac{d}{dt}M + \frac{M}{T_2} = \omega_n O - \frac{2}{\hbar} \frac{\partial H_I}{\partial b} N^* \quad (II.19)$$

$$\frac{d}{dt}O + \frac{O}{T_2} = -\omega_n M \quad (II.20)$$

A rate equation for N^* can be obtained under the assumption N^* varies slowly compared to the dynamics of M and O , and that

$$\frac{\partial H_I}{\partial b} = \text{Re}\left(\frac{\partial H_I}{\partial b}\right)_0 e^{-i\omega t} \quad (II.21)$$

Upon eliminating M and O , we obtain

$$\frac{d}{dt}N^* + \frac{N^* - N_0^*}{T_1} = -\gamma_I N^* \quad (II.22)$$

where

$$\gamma_I = 2 \left| \frac{1}{\hbar} \left(\frac{\partial H_I}{\partial b} \right)_0 \right|^2 \frac{[\omega_n^2 + \omega^2 + \frac{1}{T_2^2}] \frac{1}{T_2}}{[\omega_n^2 - \omega^2 + \frac{1}{T_2^2}]^2 + \frac{4\omega^2}{T_2^2}} \quad (II.23)$$

In the limit that the field varies on a timescale slow compared to the nuclear oscillation time $1/\omega_n$, this becomes

$$\gamma_I = \frac{2}{T_2} \left| \frac{1}{\hbar \omega_n} \left(\frac{\partial H_I}{\partial b} \right)_0 \right|^2 \quad (II.24)$$

In the limit that $\frac{\partial H_I}{\partial b}$ oscillates on resonance with the nuclear polarization ($\omega^2 = \omega_n^2 + \frac{1}{T_2^2}$), then

$$\gamma_I = \left| \frac{1}{\hbar} \left(\frac{\partial H_I}{\partial b} \right)_0 \right|^2 T_2 \quad (II.25)$$

These limits are significant in terms of constructing a coherent fusion scenario. The two fusion states constitute a two-level system with gain or loss initially, depending on whether the virtual reaction is exothermic or endothermic. The line width is determined by T_2 for the specific reaction. In the case of strong-force mediated

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decays, T_2 will be very small and the resonance will be quite broad, whereas for the reactions dominated by beta decay the lines will be very narrow.

The rate of formation of real decay products for a specific channel can be found through

$$\Gamma_i = \gamma_i |N^* - N_0^*| \quad (II.26)$$

where γ_i is the decay rate for the upper state fusion product. The time constant T_1 is related to the incoherent decay rates through

$$\frac{1}{T_1} = \sum_i \gamma_i \quad (II.27)$$

III. Semiclassical Hamiltonian Diagonalization

The form of the semiclassical hamiltonian

$$\hat{H} = \frac{1}{2} \hbar \omega_n \hat{\Sigma}_z + \frac{\partial H_I}{\partial b} \hat{\Sigma}_x \quad (III.1)$$

suggests that diagonalization can be performed through a rotation to yield

$$\hat{H} = \frac{1}{2} \hbar \omega'_n \hat{\Sigma}'_z \quad (III.2)$$

where the frequency of the rotated system is

$$\omega'_n = \sqrt{\omega_n^2 + \left(\frac{2}{\hbar} \frac{\partial H_I}{\partial b}\right)^2} \quad (III.3)$$

The eigenvalues of the hamiltonian are

$$E_m = \frac{1}{2} \hbar \omega'_n m \quad (III.4)$$

where $m = -N_{kl}, \dots, N_{kl}$.

The rotation is accomplished through the use of a unitary transformation

$$\hat{H}' = e^{i\hat{R}} \hat{H} e^{-i\hat{R}} \quad (III.5)$$

where the operator \hat{R} is linear in $\hat{\Sigma}_y$

$$\hat{R} = \frac{1}{2} \tan^{-1} \left[\frac{2}{\hbar \omega_n} \frac{\partial H_I}{\partial b} \right] \hat{\Sigma}_y \quad (III.6)$$

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The picture which follows of the coupled lattice-nuclear system in this scenario is that the system possesses dressed states in which the fusion number is mixed with quantum numbers of the macroscopic system. To lowest order, a system which has an undressed fusion number equal to zero will evolve to the ground state of the dressed system with dressed fusion number equal also to zero. Due to the mixing, this dressed ground state will decay with a rate

$$\begin{aligned}\Gamma &= \sum_i \Gamma_i = \gamma_I |N^*| \\ &= \frac{2}{T_2} \left| \frac{1}{\hbar \omega_n} \left(\frac{\partial H_I}{\partial b} \right)_0 \right|^2 N_{kl}\end{aligned}\quad (III.7)$$

assuming that $\frac{\partial H_I}{\partial b}$ is at low frequency. This decay rate is small (Typical decay rates of the order of $10^{-50} - 10^{-100} \text{ sec}^{-1}$ for charged nucleons). In order to obtain observable decay rates, transitions which change the fusion number are essential. In the following sections we shall use the dressed state picture to obtain dressed terms which raise and lower the fusion number.

IV. Lattice Dynamics

We now consider the lattice dynamics under the assumption that the nuclear polarization is semiclassical. The hamiltonian for the lattice is

$$\widehat{H} = \widehat{H}_L + \widehat{H}_I \quad (IV.1)$$

We shall restrict ourselves to single-mode interaction in this section. In this case the lattice hamiltonian is

$$\widehat{H}_L = \hbar \omega_j a^\dagger a \quad (IV.2)$$

where the creation and annihilation operators a^\dagger and a are bosonic, and satisfy the commutation relations

$$a^\dagger a - a a^\dagger = -1 \quad (IV.3)$$

The interaction hamiltonian is will be taken to be linear

$$\widehat{H}_I = \frac{\partial H_I}{\partial a} (a^\dagger + a) \quad (IV.4)$$

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where the derivative $\frac{\partial H_I}{\partial a}$ is discussed further below and in Appendix A.

As an example, we consider the case of an electric transition, such as a $d + d$ coherent reaction which would interact through an E2 multipole. In this case, the interaction can be derived from a consideration of the potential operator, which in the coulomb limit is

$$\hat{\Phi}(\mathbf{r}) = \sum_i \frac{Z_i e}{|\mathbf{r} - \hat{\mathbf{r}}_i|} \quad (IV.5)$$

which is valid for distances $|\mathbf{r} - \hat{\mathbf{r}}_i|$ which are small compared to the wavelength of the exchanged photon. The more general version of $\hat{\Phi}$ valid for larger distances is discussed in the appendix. The position operator of particle i is $\hat{\mathbf{r}}_i$. For a macroscopic system with collective modes we may write

$$\hat{\mathbf{r}}_i \approx \mathbf{R}_i + \sum_j \frac{\partial \hat{\mathbf{r}}_i}{\partial a_j} (a_j^\dagger + a_j) \quad (IV.6)$$

where \mathbf{R}_i is the equilibrium position of particle i . This result is valid to first order in the collective mode amplitudes. As a result, we obtain

$$\frac{\partial \Phi}{\partial a_j} = \sum_i \left(\nabla_i \frac{Z_i e}{|\mathbf{r} - \mathbf{r}_i|} \right)_{\mathbf{R}_i} \cdot \frac{\partial \hat{\mathbf{r}}_i}{\partial a_j} \quad (IV.7)$$

The expectation value of the linearized interaction hamiltonian is

$$\begin{aligned} \left\langle \frac{\partial \hat{H}_I}{\partial a} \right\rangle &= \frac{\partial H_I}{\partial a} \langle a^\dagger + a \rangle \\ &= \frac{\partial H_I}{\partial a} \Omega \end{aligned} \quad (IV.8)$$

where we have defined $\Omega = \langle a^\dagger + a \rangle$. In general $\frac{\partial H_I}{\partial a}$ will be a function of space, although we have assumed it to be uniform in the previous two sections. We will require a second quantity defined by

$$\Upsilon = \left\langle \frac{1}{i} (a^\dagger - a) \right\rangle \quad (IV.9)$$

The time evolution of these expectation values is given by

$$\frac{d\Omega}{dt} + \omega_j \Upsilon = 0 \quad (IV.10)$$

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$$\frac{d\Upsilon}{dt} - \omega_j \Omega = \frac{2}{\hbar} \left(\frac{\partial H_I}{\partial a} \right) \quad (IV.11)$$

Similar equations arise in laser physics, and correspond to the evolution of the electric field in a resonant cavity. In our case, the oscillation frequency of the interaction hamiltonian will in general not be well-matched to the cavity frequency ω_j . In the presence of damping, these equations become

$$\frac{d\Omega}{dt} + \frac{\omega_j \Omega}{2Q} + \omega_j \Upsilon = 0 \quad (IV.12)$$

$$\frac{d\Upsilon}{dt} + \frac{\omega_j \Upsilon}{2Q} - \omega_j \Omega = \frac{2}{\hbar} \left(\frac{\partial H_I}{\partial a} \right) \quad (IV.13)$$

where Q is the quality factor of the mode.

A possible coherent fusion scenario which might be proposed is one in which the nuclear polarization is driven at low frequency (ω_j). The nuclear system is initially inverted in the case of exothermic reactions and, if so, there is the possibility that the low frequency mode is driven. We can analyze this scenario within the framework of our model by noting that the classical nuclear polarization is defined in terms of the nuclear polarization expectation value

$$\begin{aligned} \frac{\partial H_I}{\partial a} &= \langle \frac{\partial \hat{H}_I}{\partial a} \rangle \\ &= \frac{\partial^2 H_I}{\partial a \partial b} \langle \Sigma_x \rangle \end{aligned} \quad (IV.14)$$

If we assume that the interaction hamiltonian is approximately sinusoidal, then we may use the results of section II to relate the lattice polarization to the nuclear polarization. If we assume that $\frac{\partial H_I}{\partial a}(t) = R_e(\frac{\partial H_I}{\partial a})_0 e^{-i\omega t}$ with $(\frac{\partial H}{\partial a})_0$ slowly varying in time, then we obtain

$$\langle \Sigma_x \rangle = \frac{2}{\hbar} \frac{\partial^2 H_I}{\partial a \partial b} \frac{\omega_n}{\omega_n^2 - (\omega + i/T_2)^2} N^* \Omega \quad (IV.15)$$

The criterion which must be met in order for the mode to exponentiate in the linear regime is

$$\frac{4\omega N^*}{\omega_n T_2} \left[\frac{1}{\hbar \omega_n} \frac{\partial^2 H_I}{\partial a \partial b} \right]^2 > \frac{\omega_j}{2Q} \quad (IV.16)$$

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in the case of an exothermic virtual fusion reaction. This constraint appears to be quite severe, and it is not obvious that it can be met without substantial enhancements in tunneling.

V. Coupled Lattice - Nuclear Dynamics

The hamiltonian for the combined nuclear and lattice system is

$$\widehat{H} = \widehat{H}_N + \widehat{H}_L + \widehat{H}_I \quad (V.1)$$

In terms of the operators defined in the previous sections, this can be written as

$$\widehat{H} = \frac{1}{2} \hbar \omega_n \widehat{\Sigma}_z + \frac{\partial^2 H_I}{\partial a \partial b} \widehat{\Sigma}_x (a^\dagger + a) + \hbar \omega_j a^\dagger a \quad (V.2)$$

We may diagonalize the first two terms of the hamiltonian using a rotation similar to the transformation of section III. This leads to a transformed hamiltonian given by

$$\begin{aligned} \widehat{H}' &= e^{i\widehat{R}} \widehat{H} e^{-i\widehat{R}} \\ &= \frac{1}{2} \hbar \omega'_n \widehat{\Sigma}_z + \hbar \omega_j e^{i\widehat{R}} a^\dagger a e^{-i\widehat{R}} \end{aligned} \quad (V.3)$$

The rotation operator in this case is

$$\widehat{R} = \frac{1}{2} \tan^{-1} \left[\frac{2}{\hbar} \frac{\partial^2 H_I}{\partial a \partial b} (a^\dagger + a) \right] \widehat{\Sigma}_y \quad (V.4)$$

We note that ω'_n is an operator in this formulation

$$\omega'_n = \sqrt{\omega_n^2 + \left(\frac{2}{\hbar}\right)^2 \left(\frac{\partial \widehat{H}_I}{\partial b}\right)^2} \quad (V.5)$$

We can compute the leading terms of (V.3) by assuming that \widehat{R} is small, specifically using

$$e^{i\widehat{R}} a^\dagger a e^{-i\widehat{R}} = a^\dagger a + i [\widehat{R}, a^\dagger a] + \dots \quad (V.6)$$

The resulting transformed hamiltonian is

$$\widehat{H}' = \frac{1}{2} \hbar \omega'_n \widehat{\Sigma}_z + \hbar \omega_j a^\dagger a + \frac{\omega_j}{\omega_n} \frac{\partial^2 H_I}{\partial a \partial b} \widehat{\Sigma}_y \frac{(a^\dagger - a)}{i} \quad (V.7)$$

valid to first order in $\widehat{\Sigma}_y$. The interaction term which arises is smaller than the original interaction by a factor of ω_j/ω_n . One could perform a second rotation and eliminate

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this coupling term, but given the smallness of the interaction, it does not appear at this point to be necessary.

To lowest order little happens in a system initially in the unfused state ($\hat{\Sigma}_z \Psi_0 = \pm N_{kl} \Psi_0$) of the transformed system. In the dressed state picture, the coupled system remains in the initial state (which has a small component which decays according to the results of section II), and essentially no further fusion occurs. Larger total decay rates would be obtained if transitions to states of higher fusion number could be made; such transitions require additional terms in the hamiltonian, which we consider in the following sections.

VI. A Driven Coupled Nuclear-Lattice System

In the presence of an external driving term, the hamiltonian is

$$\hat{H} = \hat{H}_N + \hat{H}_L + \hat{H}_I + \hat{H}_{ext} \quad (VI.1)$$

As before we will recast \hat{H} in terms of the operators defined previously. This yields

$$\begin{aligned} \hat{H} = & \frac{1}{2} \hbar \omega_n \hat{\Sigma}_z + \frac{\partial^2 H_I}{\partial a \partial b} \hat{\Sigma}_x (a^\dagger + a) + \hbar \omega_i a^\dagger a \\ & + \left(\frac{\partial H_{ext}}{\partial a} \right)^{(1)} (a^\dagger + a) + \left(\frac{\partial H_{ext}}{\partial a} \right)^{(2)} \frac{(a^\dagger - a)}{i} \end{aligned} \quad (VI.2)$$

where we have kept only first order terms in the external hamiltonian. The first term of the external hamiltonian is proportional to $(a^\dagger + a)$, which is a position operator. The second term is proportional to $(a^\dagger - a)/i$ which is a velocity operator.

Using the rotation of section V leads to a transformed hamiltonian

$$\begin{aligned} \hat{H}' &= e^{i\hat{R}} \hat{H} e^{-i\hat{R}} \\ &= \frac{1}{2} \hbar \omega'_n \hat{\Sigma}_z + \hbar \omega_j a^\dagger a + \frac{\omega_j}{\omega_n} \frac{\partial^2 H_I}{\partial a \partial b} \hat{\Sigma}_y \frac{(a^\dagger - a)}{i} \\ &+ \left(\frac{\partial H_{ext}}{\partial a} \right)^{(1)} (a^\dagger + a) + e^{i\hat{R}} \left(\frac{\partial H_{ext}}{\partial a} \right)^{(2)} \frac{(a^\dagger - a)}{i} e^{-i\hat{R}} \end{aligned} \quad (VI.3)$$

In this result we have kept only the lowest order term arising from the transformation of \hat{H}_L . Additionally, $(a^\dagger + a)$ commutes with \hat{R} , so that the first external term is unchanged after the transformation. To lowest order, we find

$$e^{i\hat{R}} \left(\frac{\partial H_{ext}}{\partial a} \right)^{(2)} \frac{(a^\dagger - a)}{i} e^{-i\hat{R}} =$$

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$$\left(\frac{\partial H_{ext}}{\partial a}\right)^{(2)} \frac{(a^\dagger - a)}{i} + \left(\frac{\partial H_{ext}}{\partial a}\right)^{(2)} [\hat{R}, a^\dagger - a] \quad (VI.4)$$

After performing the commutation we obtain the low order transformed hamiltonian

$$\begin{aligned} \hat{H}' = & \frac{1}{2} \hbar \omega_n' \hat{\Sigma}_z + \hbar \omega_j a^\dagger a + \frac{\omega_j}{\omega_n} \frac{\partial^2 H_I}{\partial a \partial b} \hat{\Sigma}_y \frac{(a^\dagger - a)}{i} \\ & + \left(\frac{\partial H_{ext}}{\partial a}\right)^{(1)} (a^\dagger + a) + \left(\frac{\partial H_{ext}}{\partial a}\right)^{(2)} \frac{(a^\dagger - a)}{i} \\ & - \frac{2}{\hbar \omega_n} \left(\frac{\partial H_{ext}}{\partial a}\right)^{(2)} \frac{\partial^2 H_I}{\partial a \partial b} \hat{\Sigma}_y \end{aligned} \quad (VI.5)$$

The new addition to our dressed-state hamiltonian is a term which combines the out-of-phase (velocity-dependent) external driving hamiltonian to a fusion polarization operator.

Some comments on this new term are in order. It is basically a second order effect relative to the initial lattice-nuclear coupling, except that it has the potential of being amplified since $\left(\frac{\partial H_{ext}}{\partial a}\right)^{(2)}$ may be very large. The increase in observable decay rate due to the external hamiltonian is

$$\Gamma' = \frac{8N_{kl}}{T_2} \left[\frac{1}{\hbar \omega_n} \frac{\partial^2 H_I}{\partial a \partial b} \right]^2 \frac{1}{(\hbar \omega_n)^2} \left[\left(\frac{\partial H_{ext}}{\partial a}\right)^{(2)} \right]^2 \quad (VI.6)$$

This effect increases the decay rate, but since it is assumed to be off-resonant, it appears difficult to produce substantial observable effects without enhancements of the tunneling probability.

VII. Nonlinearities and Strong Driving Terms

The only way that large enough decay rates to produce observable effects can follow from a coherent fusion theory in the absence of strong tunneling enhancement, especially in the case of weak interaction decay reactions, is if high frequency potential oscillations are developed. Such effects are not produced by first order terms in the hamiltonian, and hence one would not expect to see any coherent fusion effects in an unstressed macroscopic system in the elastic limit. Hence we are forced to consider the possibility of adding terms which are of extreme order in a and a^\dagger .

Having postulated that the presence of high order nonlinearities is required to make further progress in the theory, we face the difficulty of analyzing the system

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which is proposed. We shall begin the analysis, and we have a formulation which may in the future lead to a more tractable theory, but the discussion of this section must be viewed as the beginning of a larger and possibly involved effort.

The hamiltonian which we postulate is written as

$$\widehat{H} = \frac{1}{2}\hbar\omega_n\widehat{\Sigma}_z + \frac{\partial^2 H_I}{\partial a\partial b}\widehat{\Sigma}_x(a^\dagger + a) + \widehat{H}_L + \widehat{H}_{ext} \quad (VII.1)$$

where \widehat{H}_L and \widehat{H}_{ext} are now assumed to be highly nonlinear in a and a^\dagger . The dressed state hamiltonian is to lowest order

$$\widehat{H}' = \frac{1}{2}\hbar\omega'_n + \widehat{H}_L + i[\widehat{R}, \widehat{H}_L] + i[\widehat{R}, \widehat{H}_{ext}] \quad (VII.2)$$

where \widehat{R} is given in (V.4). Let us define

$$\widehat{\Xi} = i\left[\frac{1}{2}\tan^{-1}\left[\frac{2}{\hbar\omega_n}\frac{\partial^2 H_I}{\partial a\partial b}(a^\dagger + a)\right], \widehat{H}_L + \widehat{H}_{ext}\right] \quad (VII.3)$$

The dressed state hamiltonian becomes

$$\widehat{H}' = \frac{1}{2}\hbar\omega'_n\widehat{\Sigma}_z + \widehat{H}_L + \widehat{\Xi}\widehat{\Sigma}_y \quad (VII.4)$$

From this form of the dressed state hamiltonian we may obtain the resonance virtual fusion decay rate to be

$$\Gamma' = \frac{N_{kl}T_2}{\hbar^2} |\langle \widehat{\Xi}(\omega = \sqrt{\omega_n^2 + 1/T_2^2}) \rangle|^2 \quad (VII.5)$$

For a frequency-dependent nonlinear interaction matrix element, we may generalize this result to

$$\Gamma' = \frac{2N_{kl}}{\hbar^2} \int_0^\infty |\langle \Xi(\omega) \rangle|^2 \frac{[\omega_n^2 + \omega^2 + 1/T_2^2]}{[\omega_n^2 - \omega^2 + 1/T_2^2]^2 + 4\omega^2/T_2^2} d\omega \quad (VII.6)$$

This result is useful as a formal result for the incoherent decay of a coupled system. It is not easily amenable to further quantification in the absence of models for \widehat{H}_L and \widehat{H}_{ext} which are tractable.

We note that there is an alternate approach to the computation of the dressed state interaction term. In this case we discard a and a^\dagger as the primary macroscopic operators, and work instead directly with the individual particle position and momentum operators. We consider the coupled lattice-nuclear hamiltonian

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$$\widehat{H} = \frac{1}{2}\hbar\omega_n\widehat{\Sigma}_z + \frac{\partial\widehat{H}_I}{\partial b}\widehat{\Sigma}_x + \sum_i \frac{|\widehat{\mathbf{p}}_i|^2}{2m_i} + \sum_{i<j} V(|\widehat{\mathbf{r}}_i - \widehat{\mathbf{r}}_j|) + \widehat{H}_{ext} \quad (VII.7)$$

In this formulation, the coordinate positions \mathbf{r}_i and momenta \mathbf{p}_i are taken to be the primary operators.

The infinitesimal rotation operator is

$$\widehat{R} = \frac{1}{2} \tan^{-1} \left[\frac{2}{\hbar\omega_n} \frac{\partial\widehat{H}_I}{\partial b} \right] \widehat{\Sigma}_y \quad (VII.8)$$

The transformed hamiltonian becomes to lowest order in $\widehat{\Sigma}_y$

$$\begin{aligned} \widehat{H}' = & \frac{1}{2}\hbar\omega'_n\widehat{\Sigma}_z + \sum_i \frac{|\widehat{\mathbf{p}}_i|^2}{2m_i} + \sum_{i<j} V(|\widehat{\mathbf{r}}_i - \widehat{\mathbf{r}}_j|) + \widehat{H}_{ext} \\ & + i \frac{\widehat{\Sigma}_y}{\hbar\omega_n} \left[\frac{\partial\widehat{H}_I}{\partial b}, \sum_i \frac{|\widehat{\mathbf{p}}_i|^2}{2m_i} \right] + i \frac{\widehat{\Sigma}_y}{\hbar\omega_n} \left[\frac{\partial\widehat{H}_I}{\partial b}, \widehat{H}_{ext} \right] \end{aligned} \quad (VII.9)$$

for the case of electric E1, E1, ... transitions involving very low energy photon exchange (since $\frac{\partial\widehat{H}_I}{\partial b}$ is only a function of coordinates $\widehat{\mathbf{r}}_i$, and not momenta $\widehat{\mathbf{p}}_i$). The extension to the magnetic case is straightforward.

In terms of the coordinate-based operators, the dressed state interaction operator $\widehat{\Xi}$ is

$$\widehat{\Xi} = i \frac{1}{\hbar\omega_n} \left[\frac{\partial\widehat{H}_I}{\partial b}, \sum_i \frac{|\widehat{\mathbf{p}}_i|^2}{2m_i} \right] + i \frac{1}{\hbar\omega_n} \left[\frac{\partial\widehat{H}_I}{\partial b}, \widehat{H}_{ext} \right] \quad (VII.10)$$

In this formulation, a single dressed state fusion transition is coupled to a macroscopic transition operator. If the exchange involves a large amount of energy ($\hbar\omega_n$), then it is possible for the interaction to be resonant with the nuclear system. In the dressed state formulation, even though such a transition involves a great deal of energy, the net interaction is made of a large number of low energy coulombic photon exchanges with the nuclei. As a result, the effective interaction can be long range.

VIII. Summary and Conclusions

We have described progress which we have made towards the development of a coherent fusion theory. The premise of this type of theory is that a fusion reaction which can occur through the emission of a high energy gamma can also proceed, at

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least in principle, through the successive emission of a large number of low energy photons. In of itself, such an observation is not immediately useful, since the multi-photon process will be of high order and hence occur only weakly. If a large number of identical fusion reactions are involved in the process, then a significant enhancement of the low energy photon emission rate may be possible if the low energy photons are emitted coherently.

There are, however, two distinct problems which must be faced in order to account for the Pons-Fleischmann effect within the framework of the coherent fusion picture. Not only must nuclear energy be coupled from the microscopic to the macroscopic coherently, but some way must be found in order to overcome the coulomb barrier. Our efforts included consideration of proton-proton fusion, since it appeared to have the largest tunneling probability of all fusion reactions between charged nucleons. Although it was obvious at the outset of the work that it would be very difficult to obtain an effect sufficiently large to be observable from such premises, we found motivation from the similarities between the reported experimental observations and the qualitative features of a coherent fusion theory. We had hoped that through our investigations that some new piece of physics would turn up which would account for an enhancement in tunneling.

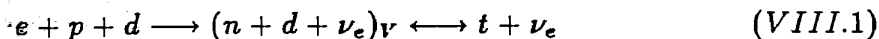
In fact, after this paper had been written and submitted, it occurred to us that two-step beta/fusion reactions involving an intermediate neutron might provide an answer to the tunneling problem. There was not time to develop a model for the new reaction and to write a new paper; it was decided to retain most of the initial paper and to supplement it with some discussion of the new ideas. Our hope is that these ideas can help in the development of a quantitative theory for the Pons-Fleischmann effect.

We have modeled systems in which coherent fusion is followed by incoherent decay. Our principal result in this area is simply making a connection between laser physics and the fusion problem. Additionally, we have found that the rates for coherent two-step fusion/beta reactions are very small, under a variety of assumptions. One of our goals was to attempt to exploit collective effects without altering the tunneling probabilities substantially in accounting for the Pons-Fleischmann effect. In this respect we have not succeeded in the case of fusion/beta reactions.

These conclusions prompted us to consider the coherent fusion mechanism on an alternate class of virtual reactions. For example, a related two-step proton-deuteron

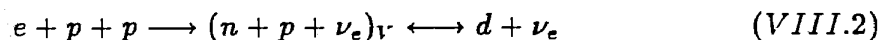
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reaction which we propose



In this type of reaction, the electron capture would precede the virtual fusion reaction. It is illustrated in Figure 2. The advantage of this type of reaction is that the fusion would occur between a neutral particle and a charged particle, and hence there is the possibility of obtaining a substantial tunneling probability for the coherent fusion branch of the reaction. This reaction would be responsible for tritium production in our new scenario.

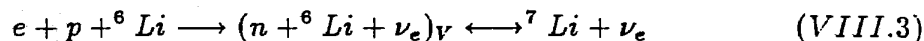
Heat production would follow from a similar beta/fusion reaction, specifically



as shown in Figure 3.

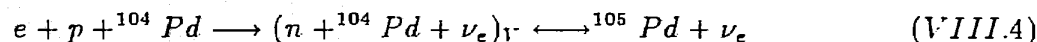
This reaction might proceed as follows: a proton would tunnel into the outer electron orbitals of a nearby metal atom, and pick up an electron through the weak interaction electron capture process. The resulting state would be virtual, since it is not energetically allowed. The fusion of the neutron and a second proton would occur through the coherent fusion (electromagnetic M1 interaction) mechanism discussed in this paper, driven by a relatively large magnetic dipole associated with neutral system tunneling. Overall, this process is somewhat related to two-photon decay. The neutrino spectrum would be continuous, and the remaining nuclear energy would be converted to heat through interaction with the current.

The basic mechanism can in principle be extended to higher Z systems. For example, a two-step reaction involving lithium is proposed:



This reaction is of interest since it can be mediated by electromagnetic E1 interaction for s-wave neutron-lithium channels, which we believe should be dominant.

The principle can be extended to higher Z coherent fusion reactions. For example, the two-step reaction



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could occur through electromagnetic E2 interaction for s-wave channels. (This proposal is in part motivated by the recent experimental observations of O'Grady at Naval Research Laboratory.) The other stable Pd isotopes could react similarly.

We have focused on proton reactions in our examples because proton would appear to be favored due to the small reduced mass. Similar reactions initiated by electron capture of deuterium or tritium are also possible, as illustrated in Figure 4.

We provide some initial discussion of the formulation of a model for this type of reaction in Appendix B. Some work remains in the development of coherent fusion theory before it becomes quantitative (the reader may provide his/her own judgement on how much). Our focus has been on mechanism, and experiments can shed light on the correctness of our premises (Is deuterium produced consistent with heat? Are neutrinos produced at substantial rates?).

In conclusion, we have proposed and explored a new scenario and several new reactions in an attempt to account for the Pons-Fleischmann effect.

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Appendix A: Second Quantization Operators

The quantities which appear in section II can be determined from the matrix element derived from the lowest order Feynman diagram for single photon exchange. This matrix element is

$$\begin{aligned} \langle \Gamma | H_I | \Gamma' \rangle = & \sum_i \sum_{kl} \langle \Gamma | \left[\frac{2}{\pi} \frac{f(K | \mathbf{r}_i - \mathbf{r}_k |)}{|\mathbf{r}_i - \mathbf{r}_k|} \right] \left[\rho_i \rho_k - \frac{\mathbf{j}_i \cdot \mathbf{j}_k}{c^2} \right] | \Gamma' \rangle \\ & + \sum_i \sum_{kl} \langle \Gamma | \left[\frac{2}{\pi} \frac{f(K | \mathbf{r}_i - \mathbf{r}_l |)}{|\mathbf{r}_i - \mathbf{r}_l|} \right] \left[\rho_i \rho_l - \frac{\mathbf{j}_i \cdot \mathbf{j}_l}{c^2} \right] | \Gamma' \rangle \end{aligned} \quad (A.1)$$

In this formula, the summation over i includes all particles in the lattice, the summation over k and l is over all pairs of hydrogen isotopes, and K is the wavevector ($2\pi/\lambda$) of the exchanged photon. The function f is defined in terms of cosine and sine integrals.

$$f(z) = Ci(z) \sin(z) - si(z) \cos(z) \quad (A.2)$$

In the low energy limit ($K \rightarrow 0$) we note that

$$\lim_{K \rightarrow 0} \frac{2}{\pi} \frac{f(K | \mathbf{r}_i - \mathbf{r}_k |)}{|\mathbf{r}_i - \mathbf{r}_k|} = \frac{1}{|\mathbf{r}_i - \mathbf{r}_k|} \quad (A.3)$$

For relativistic electrons, \mathbf{j} and ρ_i commute with \mathbf{r}_i ; in other cases (A.1) must be symmetrized with respect to noncommuting variables.

Our goal is to build up a model in which the fusion energy is coupled from the microscopic to the macroscopic. This will be easiest to accomplish when the interaction is long range, which immediately suggests that we should concentrate on low energy photon exchange (where λ is greater than the system dimensions). For example, coupling to mechanical or acoustical modes can be done with relatively low energy photons; plasmon generation in a metal will involve photons of several electron volts and will therefore be, of shorter range.

The interactions described in (A.1) are electrical or magnetic at low energy. The longest range interaction is the monopole interaction. For example, in the low energy limit where (A.3) is appropriate, then

$$\frac{1}{|\mathbf{r}_i - \mathbf{r}_k|} = \sum_{lm} \frac{4\pi}{(2l+1)} \frac{r_{<}^l}{r_{>}^{l+1}} Y_{lm}^*(\mathbf{r}_i) Y_{lm}(\mathbf{r}_k) \quad (A.4)$$

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The monopole case is where $l = 0$, and the interaction strength is proportional to $1/r$. Unfortunately, the matrix element on the microscopic scale is normally zero for an E0 transition for well-separated particles. A microscopic electric dipole (E1) transition couples to free charge with a $1/r^2$ dependence, but it requires p-wave interaction between the nucleons at the microscopic scale for light hydrogen (p and d) isotope reactions. For two-step reactions where fusion occurs first, only the s-wave interactions have any chance of contributing at low temperature. As a result, the electric quadrupole (E2) interaction will in general do best of the electric interactions for these systems, and it varies as $1/r^3$.

The allowed magnetic interactions under the assumption of microscopic s-wave interaction to even parity final states are odd-multiple (M1, M3, ...) interactions. The magnetic dipole (M1) interaction will be the strongest, and is proportional to $1/r^2$ at low energy. The dipole occurs at the nuclear microscopic half of the total interaction, while the macroscopic part of the interaction involves macroscopic current flow. Spin-spin interaction is also possible, but varies as $1/r^3$.

The dominant long range interaction (in the absence of electric and magnetic monopole transitions) is the M1 interaction, for even parity final states for which the interaction hamiltonian at low energy is customarily taken to be

$$H_I = -\mu \cdot B \quad (A.5)$$

In the case of the two-step reactions described in section VIII, the neutron need not necessarily be at low energy relative to the charged nucleus. At low energy the above arguments still hold, but at high energy p-wave terms are possible, and the coupling can in principle occur through E1 interaction.

We can simplify the matrix element through the use of the Hartree approximation. In this approximation, we separate the total macroscopic wavefunction $|\Gamma\rangle$ into a product of a local part $|\phi_\Gamma\rangle_{kl}$ which includes the two fusing hydrogen isotopes, and $|\bar{\Gamma}\rangle$ which includes the remaining part of $|\Gamma\rangle$. The electrical part of the interaction in this approximation is

$$\langle \Gamma | H_E | \Gamma' \rangle = \sum_{kl} \sum_{LM} \langle \phi_\Gamma | \rho_{LM} | \phi_{\Gamma'} \rangle_{kl} \Phi_{LM}(\mathbf{r}_{kl}) \quad (A.6)$$

where

$$\Phi_{LM}(\mathbf{r}) = \sum_i \langle \bar{\Gamma} | \frac{Z_i e Y_{LM}(\frac{\mathbf{r}-\mathbf{r}_i}{|\mathbf{r}-\mathbf{r}_i|})}{|\mathbf{r}-\mathbf{r}_i|^{L+1}} | \bar{\Gamma}' \rangle \quad (A.7)$$

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and where

$$\rho_{LM} = Q_{LM}^E = \sum_i \frac{e}{2} [1 + \tau_3(i)] r_i^L Y_{LM}^*(\hat{r}_i) \quad (A.8)$$

in the low energy limit. In this formula, we have assumed in addition that the principal interaction is long range such that $|\mathbf{r}_i - \mathbf{r}_k| = |\mathbf{r}_i - \mathbf{r}_l| = |\mathbf{r}_i - \mathbf{r}_{kl}|$. The coordinate \mathbf{r}_{kl} in this formula denotes the location of the fusion product.

In the limit that the wavelength of the exchanged photon is long compared to the nuclear scale, but otherwise arbitrary, then (A.4) is replaced by

$$\frac{2}{\pi} \frac{f(K |\mathbf{r}_i - \mathbf{r}_k|)}{|\mathbf{r}_i - \mathbf{r}_k|} = \sum_{lm} 8 \int_0^\infty \frac{k}{K+k} j_l(kr_1) j_l(kr_2) dk Y_{lm}^*(\hat{\mathbf{r}}_1) Y_{lm}(\hat{\mathbf{r}}_2) \quad (A.9)$$

and Φ_{LM} becomes

$$\Phi_{LM}(\mathbf{r}) = \sum_i \langle \bar{\Gamma} | Z_i e Y_{LM} \left(\frac{\mathbf{r} - \mathbf{r}_i}{|\mathbf{r} - \mathbf{r}_i|} \right) \frac{\sqrt{\pi}}{\Gamma(L + \frac{3}{2}) 2^{L+1}} \int_0^\infty \frac{k^{L+1}}{\omega + k} j_L(k |\mathbf{r} - \mathbf{r}_i|) dk | \bar{\Gamma}' \rangle \quad (A.10)$$

The magnetic part of the interaction becomes

$$\langle \Gamma | H_M | \Gamma' \rangle = -\frac{1}{c} \sum_{kl} \sum_{LM} \langle \phi_\Gamma | \mathbf{J}_{LM} | \phi_{\Gamma'} \rangle_{kl} \cdot \mathbf{A}_{LM}(\mathbf{r}_{kl}) \quad (A.11)$$

where

$$\langle \phi_\Gamma | \mathbf{J}_{LM} | \phi_{\Gamma'} \rangle_{kl} = \sum_i \frac{1}{2} \langle \phi_\Gamma | r_i^L Y_{LM}^* \mathbf{j}_i + \mathbf{j}_i r_i^L Y_{LM} | \phi_{\Gamma'} \rangle \quad (A.12)$$

and

$$\mathbf{A}_{LM}(\mathbf{r}) = \sum_i \langle \bar{\Gamma} | \mathbf{j}_i \left[\frac{Y_{LM}}{|\mathbf{r} - \mathbf{r}_i|^{L+1}} + \frac{Y_{LM}}{|\mathbf{r} - \mathbf{r}_i|^{L+1}} \mathbf{j}_i \right] | \bar{\Gamma} \rangle \quad (A.13)$$

The generalization to the case where the wavelength of the exchanged photon is much larger than nuclear size scales, but otherwise arbitrary, is obtained through the use of (A.9), as before.

We have defined matrix elements thus far which allow us to handle both electric and magnetic coupling for arbitrary multipolarity. We are ignoring free photon emission in the present work. At this point we shall focus on the magnetic M1 interaction, although it is clear that we are in a position to adapt our formulation to other cases.

The M1 matrix element is

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$$\begin{aligned}
\langle \Gamma | H_M | \Gamma' \rangle &= -\frac{1}{c} \sum_{kl} \sum_{M=-1}^1 \langle \phi_\Gamma | \mathbf{J}_{1M} | \phi_{\Gamma'} \rangle_{kl} \cdot \mathbf{A}_{1M}(\mathbf{r}_{kl}) \\
&= -\sum_{kl} \langle \phi_\Gamma | \boldsymbol{\mu} | \phi_{\Gamma'} \rangle_{kl} \cdot \mathbf{B}(\mathbf{r}_{kl})
\end{aligned} \tag{A.17}$$

where

$$\mathbf{B}(\mathbf{r}) = \frac{1}{c} \nabla \times \sum_i \langle \bar{\Gamma} | \frac{1}{2} (\mathbf{j}_i \frac{1}{|\mathbf{r} - \mathbf{r}_i|} + \frac{1}{|\mathbf{r} - \mathbf{r}_i|} \mathbf{j}_i) | \bar{\Gamma}' \rangle \tag{A.18}$$

and the magnetic moment is

$$\boldsymbol{\mu} = \sum_i g_i^{(l)} \mathbf{l}_i + g_i^{(s)} \mathbf{s}_i \tag{A.19}$$

Some simplification is afforded if the dipole moments are taken to be uniform for all pairs. For example, in *HD* gas at very low temperature all pairs would be in the ground state, and all molecules with identical relative *J* will possess identical moments. In this limit, we may define a spatially dependent polarization operator to be

$$O(\mathbf{r}) = \sum_{kl} \delta^3(\mathbf{r} - \mathbf{r}_{kl}) \tag{A.20}$$

In terms of these operators, the interaction matrix element becomes

$$\langle \Gamma | H_I | \Gamma' \rangle = \boldsymbol{\mu} \cdot \int O(\mathbf{r}) \langle \bar{\Gamma} | \mathbf{B}(\mathbf{r}) | \bar{\Gamma}' \rangle d^3\mathbf{r} \tag{A.21}$$

The transition to a second quantization picture can now be made. At the location \mathbf{r}_{kl} , the two hydrogen isotopes can either be fused or not. The interaction matrix element is of interest when a fusion transition occurs, either creation of a fused state (we shall adopt b_{kl}^\dagger to describe the transition to a fused state) or destruction of a fused state (b will be the annihilation operator). The second quantized version of the polarization operator is

$$\hat{O}(\mathbf{r}) = \sum_{kl} \delta^3(\mathbf{r} - \mathbf{r}_{kl}) (b_{kl}^\dagger + b_{kl}) \tag{A.22}$$

The b_{kl}^\dagger operators must be fermionic, since once two hydrogen isotopes have fused, they are assumed not to be able to fuse further.

If we define spatially dependent versions of the inversion and polarization operators

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$$\widehat{N}^*(\mathbf{r}) = \sum_{kl} \delta^3(\mathbf{r} - \mathbf{r}_{kl}) (b_{kl}^\dagger b_{kl} - b_{kl} b_{kl}^\dagger) \quad (\text{A.23})$$

and

$$\widehat{M}(\mathbf{r}) = \sum_{kl} \delta^3(\mathbf{r} - \mathbf{r}_{kl}) \frac{(b_{kl}^\dagger - b_{kl})}{i} \quad (\text{A.24})$$

then we would obtain a spatially-dependent version of the equations (II.18 - II.20).

If $\mathbf{B}(\mathbf{r})$ is considered to be an operator (in terms of $\widehat{\mathbf{r}}_i$), then the interaction matrix element becomes

$$\langle \Gamma | H_I | \Gamma' \rangle = \langle \Gamma | \mu \cdot \int \widehat{\mathbf{O}}(\mathbf{r}) \widehat{\mathbf{B}}(\mathbf{r}) d^3\mathbf{r} | \Gamma' \rangle \quad (\text{A.25})$$

This is ultimately the basis for the discussion of section VII.

We have chosen to work with an assumption that the interaction is uniform in the vicinity of the fusing hydrogen isotopes. This corresponds to the Dicke superradiant limit of this type of model, and allows us to exploit the rotation transformations introduced in section III. Under this assumption, (A.12) becomes

$$\langle \Gamma | H_I | \Gamma' \rangle = \langle \Gamma | \mu \cdot \int \widehat{\mathbf{O}}(\mathbf{r}) d^3\mathbf{r} \widehat{\mathbf{B}} | \Gamma' \rangle \quad (\text{A.26})$$

The integral in (A.13) is computed

$$\int \widehat{\mathbf{O}}(\mathbf{r}) d^3\mathbf{r} = \sum_{kl} (b_{kl}^\dagger + b_{kl}) \quad (\text{A.27})$$

which is a space-independent version of $\widehat{\mathbf{O}}$ which we have used in section II. Using $\widehat{\mu} = \mu \sum_{kl} (b_{kl}^\dagger + b_{kl})$, we obtain

$$\langle \Gamma | H_I | \Gamma \rangle = \langle \Gamma | \widehat{\mu} \widehat{\mathbf{B}} | \Gamma \rangle \quad (\text{A.28})$$

which is the premise of equation (II.4).

In order to free ourselves from a particular multipolarity, we will work in terms of \widehat{H}_I . For magnetic dipole interaction, we define

$$\begin{aligned} \widehat{H}_I &= \sum_{kl} \frac{\partial \widehat{H}_I}{\partial b_{kl}} (b_{kl}^\dagger + b_{kl}) \\ &\approx \frac{\partial \widehat{H}_I}{\partial b} \widehat{\mathbf{O}} = \frac{\partial \widehat{H}_I}{\partial b} \widehat{\Sigma}_x \end{aligned} \quad (\text{A.29})$$

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For section IV, we have

$$\begin{aligned}\widehat{H}_I &= \sum_{ij} (\nabla_i \widehat{H}_I) \cdot \frac{\partial \mathbf{r}_i}{\partial \mathbf{a}_j} (a_j^\dagger + a_j) \\ &= \sum_j \frac{\partial \widehat{H}_I}{\partial \mathbf{a}_j} (a_j^\dagger + a_j)\end{aligned}\tag{A.30}$$

For section V, we extend this to

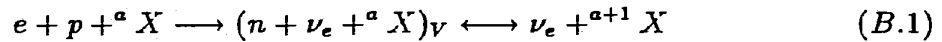
$$\begin{aligned}\widehat{H}_I &= \sum_i \sum_{kl} \frac{\partial^2 \widehat{H}_I}{\partial a_i \partial b_{kl}} (a_i^\dagger + a_i) (b_{kl}^\dagger + b_{kl}) \\ &\approx \frac{\partial^2 \widehat{H}_I}{\partial \mathbf{a} \partial \mathbf{b}} \left(\sum_i a_i^\dagger + a_i \right) \widehat{\Sigma}_x\end{aligned}\tag{A.31}$$

With this type of formulation, we may describe E1, E2 and M1 interactions on the same formal basis.

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Appendix B:

We wish to explore the extension of our formulation to reactions where electron capture occurs before fusion. Our formulation will focus on the generic two-step reaction.



This reaction is fundamentally more complicated than the fusion/beta reactions considered earlier since the neutron all neutrino and neutron energies must be included.

We begin by considering the microscopic problem of three initial particles (e, p and ${}^a X$). The Schrödinger equation which we shall adopt is written as

$$i\hbar \frac{\partial}{\partial t} \begin{bmatrix} \Psi_1 \\ \Psi_2 \\ \Psi_3 \end{bmatrix} = \begin{bmatrix} H_1 & H_W & 0 \\ H_W & H_2 & \widehat{H}_I \\ 0 & \widehat{H}_I & H_3 \end{bmatrix} \begin{bmatrix} \Psi_1 \\ \Psi_2 \\ \Psi_3 \end{bmatrix} + \widehat{H}_L \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \Psi_1 \\ \Psi_2 \\ \Psi_3 \end{bmatrix} \quad (B.2)$$

We have expanded out the creation and annihilation operator explicitly in this notation. The hamiltonian H_1 contains terms appropriate for the three initial particles (e, p and ${}^a X$) and the lattice, and Ψ_1 contains coordinates for the initial three particles and the lattice. The hamiltonians H_2 and H_3 contain terms appropriate for the three intermediate (and final) state particles ($n, \nu_e, {}^a X$), in the crude picture that ${}^{a+1}X$ is simply a bound state of the $n + {}^a X$ system. The collection of particles described by H_2 and H_3 are identical, and in this sense H_2 and H_3 are the same unless we find some way to distinguish between the spaces on which they operate. We shall employ projection operators P and Q which will give meaning to our separating H_2 and H_3 . Specifically, we define

$$H_2 = PHP \quad (B.3)$$

$$H_3 = QHQ \quad (B.4)$$

where P projects out states in which the neutron is bound.

The electron capture occurs through the weak interaction, which is accounted for in the off-diagonal H_W in (B.2). The electromagnetic transitions which drive the coherent fusion process are in \widehat{H}_I . The hats in this equation refer to lattice operators. As before, the coupling between a fusion reaction and the lattice is assumed to be dominated by low order and low energy lattice transitions.

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The generalization of the transformation to the dressed state picture is accomplished through a rotation similar to the one used in section III. The infinitesimal rotation operator of interest would be

$$\hat{R} = \frac{1}{2} \tan^{-1} \left[\frac{2}{H_2 - H_3} \hat{H}_I \right] \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & i \\ 0 & -i & 0 \end{bmatrix} \quad (B.5)$$

if \hat{H}_I commuted with $H_2 - H_3$. The transformed hamiltonian would then be approximately

$$\begin{aligned} \hat{H}' = & \begin{bmatrix} H_1 & H_W & 0 \\ H_W & H_2 & 0 \\ 0 & 0 & H_3 \end{bmatrix} + \hat{H}_L \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \\ & + i \frac{1}{H_2 - H_3} [\hat{H}_I, \hat{H}_L] \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & i \\ 0 & -i & 0 \end{bmatrix} \end{aligned} \quad (B.6)$$

We would then extend our definition of the local dressed state interaction operator $\hat{\Xi}_{kl}$ to be

$$\hat{\Xi}_{kl} = i \frac{1}{H_2 - H_3} [\hat{H}_I, \hat{H}_L + \hat{H}_{ext}] \quad (B.7)$$

following equation (VII.11), and where we have included an external driving hamiltonian.

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Acknowledgements

The author would like to acknowledge the support of his friends in the course of this work, which was supported under DOE grant number DE-FG02-89ER14012.

References

- 1 M. Fleischmann and S. Pons, *J. Electroanalytic Chemistry*, **261** 301 (1989).
- 2 R. D. Petrasso, X. Chen, K. W. Wenzel, R. R. Parker, C. K. Li, C. Fiore, *Nature* **339** 183 (1989).
M. Fleischmann, S. Pons, and R. J. Hoffman *Nature*, **339** 667 (1989).
R. D. Petrasso, X. Chen, K. W. Wenzel, R. R. Parker, C. K. Li, C. Fiore, *Nature* **339** 667 (1989).
- 3 M. Gai, S. L. Rugari, R. H. France, B. J. Lund, Z. Zhao, A. J. Davenport, H. S. Isaacs and K. G. Lynn, "Upper limits on emission rates of neutrons and gamma-rays from cold fusion in deuterided metals," *Nature* **340** 29 (1989).
- 4 H. Hsuan, D. M. Manos, S. Cohen, S. Cowley, R. Motley, A. L. Roquemore, T. Saito, J. Timberlake, W. Ayers, T. Bennett, M. Bitter, F. E. Cecil, J. Cuthbertson, J. Dong, H. F. Dylla, J. Evans, H. Furth, L. Grisham, H. Hendel, K. Hill, R. Kulsrud, D. Meade, S. S. Medley, D. Mueller, E. Nieshmidt, R. Shoemaker and J. Thomas, "Lack of neutron and gamma radiation from PPPL's cold fusion experiments," presented at the Workshop on Cold Fusion Phenomena at Santa Fe, May 1989.
- 5 N. S. Lewis and C. A. Barnes, "Calorimetry, neutron flux, gamma flux, and tritium yield from electrochemically charged palladium in D_2O ," presented at the Workshop on Cold Fusion Phenomena at Santa Fe, May 1989.
- 6 J. F. Ziegler, T. H. Zabel, J. J. Cuomo, V. A. Brusic, G. S. Cargill, III, E. J. O'Sullivan and A. D. Marwick, *Phys. Rev. Lett*, **62** 2929 (1989).
- 7 D. Albagli, R. Ballinger, V. Cammarata, X. Chen, R. M. Crooks, C. Fiore, M. J. P. Gaudreau, I. Hwang, C. K. Li, P. Lindsay, S. C. Luckhardt, R. R. Parker, R. D. Petrasso, M. O. Schloh, K. W. Wenzel and M. Wrighton, "Measurement and Analysis of Neutron and Gamma Ray Emission Rates, Other Fusion Products,

-46-

and Power in Electrochemical Cells Having Pd Cathodes," Workshop on Cold Fusion Proceedings to appear in *J. Fusion Energy* (1989).

8 P. L. Hagelstein, Proceedings of the Cold Fusion Workshop, *J. Fusion Energy*, in press.

9 A. deShalit and H. Feshbach, *Theoretical Nuclear Physics*, Vol. 1, John Wiley and Sons, N.Y. (1974).

10 N. B. Gove and M. J. Martin, *Nuclear Data Tables*, 10, 205 (1971).

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Figure Captions

Figure 1: Schematic of two-step fusion/beta reaction $p + d \longleftrightarrow (^3He)_V \longrightarrow t + e^+ + \nu_e$. L stands for lattice in this diagram, and the electromagnetic exchange of many low energy photons is indicated here by a double photon line.

Figure 2: Two-step coherent beta/fusion reaction $p + d + e \longrightarrow (n + d + \nu_e)_V \longleftrightarrow t + \nu_e$.

Figure 3: Two-step coherent beta/fusion reaction $p + p + e \longrightarrow (n + p + \nu_e)_V \longleftrightarrow d + \nu_e$.

Figure 4: Example of a coherent fusion reaction involving electron capture by a deuteron.

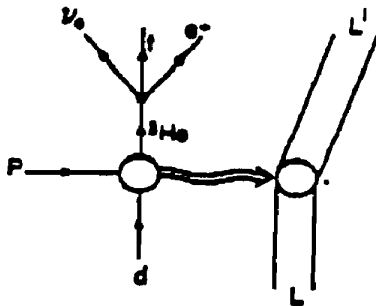


Fig. 1

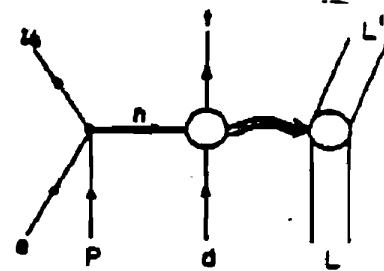


Fig. 2

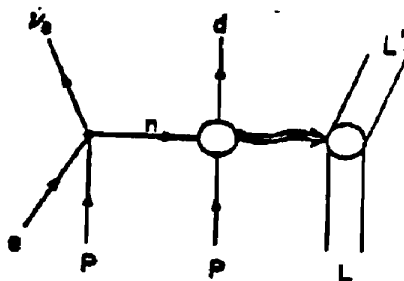


Fig. 3

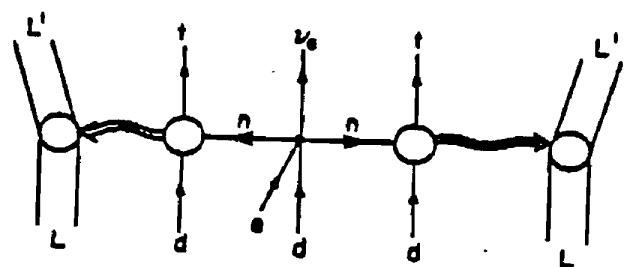


Fig. 4

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Florence and Sam:

Sorry for taking so long to respond. I have been up to my gills in sorting out theory. I think that the new theory stuff is getting to be in very good shape - we'll see if my colleagues agree tomorrow.

I have attempted to provide by best guess from the theory as to what is required and what the applications are. The experimentalists think that there are no positrons, or at least not very many, in the cells producing tritium. This prompted me to go to capture-first models.

In the new scheme, alas, I cannot get ${}^3\text{He}$. I should be able to turn ${}^3\text{He}$ into ${}^4\text{He}$, but this is not of much use. Getting things going initially - I think that introducing some tritium would help (tritium production is exponential and I now think the tritium is better than deuterium is better than protons as a source of neutrons), and spin-polarizing (which is new and untried) should also make a difference. Magnetic fields should also help. I no longer think that fast particles help start things off.

Electronic transition laser materials are still in, but require production of an unstable isotope to drive. For example, $e + d + d + {}^{26}\text{Mg} \rightarrow (2n + v_e + d + {}^{26}\text{Mg})_v \leftrightarrow v_e + t + {}^{27}\text{Mg}$ and the ${}^{27}\text{Mg}$ later decays producing decay products which could be made to drive electronic transition lasers. The vibrational laser and maser claims are still physically possible, but would work through having either a very hot region supplying the optical phonons - I am not certain that we can get the fusion to drive the optical phonons directly (I doubt it), but it is something which in time I should be able to clarify.

I will call tomorrow. I hope that this is of some use.

-PH

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According to current version of coherent theory, here is what is required:

(1) Source of virtual or off-shell neutrons: H, D, T are only possible sources. T is better than D, which is better than H. ($H = {}^1H, D = {}^2H, T = {}^3H$).

(2) Source of electrons at "high" density. Electron capture part is linear in electron density, and local electron density of $\sim 1/a_0^3$ is right ballpark ($a_0 = 0.529\text{\AA}$).

(3) Target nuclei for virtual neutron pickup: M1 pickup is allowed between any two ground state nuclei which have $|J_i - J_f| = 1/2$ and $\pi_i - \pi_f = 1$, where J_i and π_i are initial total angular momentum and parity, and J_f and π_f are final state total angular momentum and parity. E1 pickup has $|J_i - J_f| = \frac{1}{2}, \frac{3}{2}$ and $\pi_i - \pi_f = -1$. I believe that you were sent tables of the M1 and E1 isotopes. For example, 1H can pick up a virtual neutron to make 2H through M1 interaction.

(4) Source of coherence, or macroscopic polarizations. There are at least 3 distinct ways to do this.

- a) Spin-polarize the electrons which are picked up. Some degree of polarization occurs in the presence of a magnetic field in Pd and Ti for example.
- b) Spin-polarize the source of neutrons. (i.e. spin align the deuterium first)
- c) Spin-polarize the target nucleons.
- d) It may be possible to achieve electric polarization through alignment of quadrupole moments of the target nuclei.

[I believe that it is well known how to do this. Spin-aligned DT fusion experiments have been done. Nuclear spin alignment could be accomplished through selective excitation of hyperfine transitions using NMR techniques].

(5) Source of stimulation of coherent nuclear transitions.

- a) For M1, M2, M3 etc. transitions, this implies macroscopic current flow, possibly in conjunction with magnetically permeable materials to guide and enhance the H-field. The only requirement of the field is that it stimulate the net emission or absorption of low energy photons from the coherent nuclei.
- b) For E1, E2, E3 etc. transitions, this implies macroscopic excess charge density, possibly in conjunction with dielectric materials to increase local

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field strength. Again, the only real requirement be that it cause absorption or emission from the coherent nuclei.

c) At high frequency, macroscopic magnetic fields give rise to induced electric fields, and time-changing electric fields give rise to induced magnetic fields. Hence excess surface charge can be used at high frequency to stimulate M1 transitions and so forth.

d) Radio-wave or microwave sources should be able to drive the coherent nuclear magnetic or electric dipoles. In principle, lasers can do it but the coherence size may be reduced.

(6) The above considerations are general for any coherent fusion device. Special applications might include:

a) Heat generation if the virtual neutron pick-up is to an unstable final state. For example, $^{26}\text{Mg} + n \rightarrow ^{27}\text{Mg}$ where the final product has a decay time of 9.45 m. Also $^7\text{Li} + n \rightarrow ^8\text{Li}$, where ^8Li decays in 0.844 sec. There are many such systems.

b) Heat generation may also be possible through stimulation of a macroscopic coherent magnetic or electric dipole in the presence of highly nonlinear media - for example, a highly stressed lattice. In this case there is the potential for multi-soft-photon emission. This applies both to current flow and M1, M2 etc. transitions (if the nonlinearity of the lattice affects the resistance) and excess charge (if the nonlinearity affects surface charge motion).

c) These systems should be strong sources of neutrinos.

d) Neutron pick-up should be assisted in E1 and M1 systems, and this allows production of isotopes in quantity for research applications. Of possible interest is ^{13}C , ^{134}Cs , ^{55}Fe and ^{59}Ni .

e) Neutron pick-up can be used on radioactive substances. The idea would be to add neutrons and increase the radioactivity (shorten the lifetime), such that some types of radioactive waste could be "neutralized". For example, ^{239}Pu can pick up a virtual neutron through M1 interaction.

f) (Use as a gamma source) Gamma emission should be possible through virtual neutron pick-up on high-Z elements. For example, ^{222}Rn has a

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lifetime of 3.824 d. If it could pick up a neutron coherently, then it would decay faster (I think), and I am pretty sure that the decay should involve a gamma pathway in a daughter.

g) (Use as a β source) β^+ and β^- emission are both in principle possible by selecting a final state with a β -decay path. This could provide an interesting source of β -radiation which can be at very high levels and controllable.

h) (Use as an x-ray source). The production of unstable isotopes (preferably short-lived at the second to minute level) will be accompanied by hard radiation (α, β, γ etc.). This radiation will be accompanied by secondary x-ray emission. A source based on this could be of tremendous use. The ^{26}Mg pickup to ^{27}Mg is my favorite candidate, and any element could serve as the UV or x-ray converter.

i) Driving chemical reactions: The production of unstable short lived isotopes would provide a source of nonthermal excitation which could be used to drive chemical reactions otherwise inhibited by an energy barrier. Cracking of N_2 near a coherent fusing surface containing ^{26}Mg is an example.

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What is claimed is:

1. Fusion apparatus comprising:
fusible material; and
excitation apparatus for initiating coherent fusion of said material.
2. The apparatus of claim 1 further comprising a reactor vessel.
3. The apparatus of claim 1 wherein said excitation apparatus permits interaction of cosmic rays with said fusible material.
4. The apparatus of claim 1 wherein said excitation apparatus includes a source of α -particles.
5. The apparatus of claim 1 wherein said excitation apparatus creates non-linear effects in said reactor vessel.
6. The apparatus of claim 5 wherein said non-linear effects result from application of acoustical vibration.
7. The apparatus of claim 5 wherein said non-linear effects result from application of electrical fields.
8. The apparatus of claim 1 wherein said excitation apparatus is cosmic-ray permeable; and
further comprises a source of α -particles, a source of acoustical vibrations and a source of electric fields.
9. The apparatus of claim 1 wherein said fusible material includes hydrogen and deuterium whose relative abundance has been adjusted to optimize coherent fusion.
10. The apparatus of claim 8 wherein said fusible material includes hydrogen and deuterium whose relative abundance has been adjusted to optimize coherent fusion.
11. Fusion apparatus comprising:
fusible material; and
apparatus for coupling said fusible material to a quantized mode such that said coupling is strong enough to initiate coherent fusion.
12. The apparatus of claim 11 wherein said quantized mode is mechanical, electrical, magnetic, or composite.
13. The apparatus of claim 2 wherein said quantized mode has a wavelength.
14. The apparatus of claim 13 wherein said mode is generated by one or more oscillators.
15. The apparatus of claim 14 wherein said oscillator generates electromagnetic radiation.

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16. The apparatus of claim 15 wherein said electromagnetic radiation is in the frequency range.
17. The apparatus of claim 14 wherein said oscillator includes a variable quality factor (Q) resonator.
18. The apparatus of claim 11 wherein said apparatus for coupling is an electrically conductive containment vessel.
19. The apparatus of claim 18 wherein said containment vessel has a radially symmetric geometry.
20. The apparatus of claim 19 wherein said geometry is a cylinder, sphere, or toroid.
21. The apparatus of claim 18 wherein said containment vessel is provided with external, radially disposed, rod-like projections for coupling said plasmon mode to said fusible material.
22. The apparatus of claim 21 wherein said rod-like projections are positioned on isopotential curves.
23. The apparatus of claim 21 wherein one or more of said projections is individually coupled to high quality factor (Q) resonators.
24. The apparatus of claim 11 wherein said fusible material includes hydrogen.
25. The apparatus of claim 11 wherein said fusible material includes deuterium.
26. The apparatus of claim 11 wherein said fusible material includes a mixture of hydrogen and deuterium.
27. The apparatus of claim 26 wherein said mixture is adjusted to optimize the coherent fusion rate.
28. The apparatus of claim 11 wherein said fusible material is a gas.
29. The apparatus of claim 11 wherein said fusible material is a liquid.
30. The apparatus of claim 11 wherein said fusible material is a solid.
31. The apparatus of claim 11 wherein said fusible material is maintained at a cryogenic temperature? to reduce P-D exchange?
32. The apparatus of claim 30 wherein said solid is a lattice.
33. The apparatus of claim 32 wherein said lattice is ice or a metal hydride.
34. The apparatus of claim 11 wherein said fusible material is provided with a proton source.
35. The apparatus of claim 11 wherein by-products of coherent fusion are removed from said containment vessel using a circulation loop.

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36. The apparatus of claim 35 wherein said by-product is tritium.
37. The apparatus of claim 11 wherein usable power is extracted with a computer-controlled variable load electrically connected in series to said coupling apparatus.
38. The apparatus of claim 11 wherein usable power is extracted with a computer-controlled variable load electrically connected in parallel to said coupling apparatus.
39. The apparatus of claim 11 wherein said coherent fusion is stopped by selective introduction of a proton excess.
40. The apparatus of claim 11 wherein said coherent fusion is stopped by uncoupling said fusible material from said quantized mode.
41. The apparatus of claim 11 wherein said coupling is accomplished by radially polarizing insulating crystals.
42. The apparatus of claim 40 or 41 wherein microwaves are used to effect polarization.
43. Fusion apparatus comprising:
 - fusible material contained within an electrically conductive containment vessel provided with radially disposed rod-like projections which are electrically connected in series with an oscillator; and
 - a computer-controlled variable load to extract usable energy from coherent fusion.
44. The apparatus of claim 43 wherein said oscillator generates high frequency electromagnetic radiation.
45. The apparatus of claim 44 wherein said electromagnetic radiation is in the gigahertz to terahertz frequency range.
46. The apparatus of claim 44 wherein said oscillator includes a variable quality factor (Q) resonator.
47. The apparatus of claim 43 wherein said containment vessel has a radially symmetric geometry.
48. The apparatus of claim 47 wherein said geometry is a cylinder, sphere, or toroid.
49. The apparatus of claim 43 wherein said rod-like projections are positioned on isopotential curves.
50. The apparatus of claim 43 wherein one or more of said projections is individually coupled to high quality factor (Q) resonators.
51. The apparatus of claim 43 wherein said fusible material includes hydrogen.
52. The apparatus of claim 43 wherein said fusible material includes deuterium.

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53. The apparatus of claim 43 wherein said fusible material includes a mixture of hydrogen and deuterium.

54. The apparatus of claim 43 wherein said mixture is adjusted to optimize the coherent fusion rate.

55. The apparatus of claim 43 wherein said fusible material is a gas.

56. The apparatus of claim 43 wherein said fusible material is a liquid.

57. The apparatus of claim 43 wherein said fusible material is a solid.

58. The apparatus of claim 43 wherein said fusible material is maintained at a cryogenic temperature.

59. The apparatus of claim 57 wherein said solid is a lattice.

60. The apparatus of claim 59 wherein said lattice is ice or a metal hydride.

61. The apparatus of claim 43 wherein said fusible material is provided with a proton source.

62. The apparatus of claim 43 wherein by-products of coherent fusion are removed from said containment vessel using a circulation loop.

63. The apparatus of claim 62 wherein said by-product is tritium.

64. The apparatus of claim 43 wherein said computer-controlled variable load is electrically connected in series or parallel to said coupling apparatus.

65. The apparatus of claim 43 wherein said coherent fusion is stopped by selective introduction of a proton excess.

66. The apparatus of claim 43 wherein said coherent fusion is stopped by disconnecting said oscillator from said containment vessel.

67. Fusion apparatus comprising:

fusible material contained within an electrically conductive containment vessel permeable to cosmic rays provided with radially disposed rod-like projections which are electrically connected in series with an oscillator; and

a computer-controlled variable load to extract usable energy from coherent fusion.

68. The apparatus of claim 67 further comprising an α -particle source.

69. The apparatus of claim 67 wherein said oscillator generates low frequency.

70. The apparatus of claim 69 wherein said electromagnetic radiation is in the frequency range.

71. The apparatus of claim 69 wherein said oscillator includes a variable quality factor (Q) resonator.

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72. The apparatus of claim 67 wherein said containment vessel has a radially symmetric geometry.

73. The apparatus of claim 72 wherein said geometry is a cylinder, sphere, or toroid.

74. The apparatus of claim 67 wherein said rod-like projections are positioned on isopotential curves.

75. The apparatus of claim 67 wherein one or more of said projections is individually coupled to high quality factor (Q) resonators.

76. The apparatus of claim 67 wherein said fusible material includes hydrogen.

77. The apparatus of claim 67 wherein said fusible material includes deuterium.

78. The apparatus of claim 67 wherein said fusible material includes a mixture of hydrogen and deuterium.

79. The apparatus of claim 78 wherein said mixture is adjusted to optimize the coherent fusion rate.

80. The apparatus of claim 67 wherein said fusible material is a gas.

81. The apparatus of claim 67 wherein said fusible material is a liquid.

82. The apparatus of claim 67 wherein said fusible material is a solid.

83. The apparatus of claim 67 wherein said fusible material is maintained at a cryogenic temperature.

84. The apparatus of claim 82 wherein said solid is a lattice.

85. The apparatus of claim 84 wherein said lattice is ice or a metal hydride.

86. The apparatus of claim 67 wherein said fusible material is provided with a proton source.

87. The apparatus of claim 67 wherein by-products of coherent fusion are removed from said containment vessel using a circulation loop.

88. The apparatus of claim 87 wherein said by-product is tritium.

89. The apparatus of claim 67 wherein said computer-controlled variable load is electrically connected in series or parallel to said coupling apparatus.

90. The apparatus of claim 67 wherein said coherent fusion is stopped by selective introduction of a proton excess.

91. The apparatus of claim 67 wherein said coherent fusion is stopped by disconnecting said oscillator from said containment vessel.

92. The apparatus of claim 2, 18, 43 or 67 wherein said vessel consists of metal resistant to enhanced fission.

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93. The apparatus of claim 92 wherein said metal is selected from a group consisting of metals having atomic numbers less than or equal to twenty-six.

94. The apparatus of claim 92 wherein said metal is Ti or Fe.

95. Fusion apparatus comprising:

fusible material contained within an insulating containment vessel surrounded by radially disposed polarizable crystals;

a microwave generator for polarization coupled to said crystals; and

an apparatus for extracting usable energy from coherent fusion.

96. The apparatus of claim 95 wherein said containment vessel has a radially symmetric geometry.

97. The apparatus of claim 96 wherein said geometry is a cylinder, sphere or toroid.

98. The apparatus of claim 95 wherein said fusible material includes hydrogen.

99. The apparatus of claim 95 wherein said fusible material includes deuterium.

100. The apparatus of claim 95 wherein said fusible material includes a mixture of hydrogen and deuterium.

101. The apparatus of claim 95 wherein said mixture is adjusted to optimize the coherent fusion rate.

102. The apparatus of claim 95 wherein said fusible material is a gas.

103. The apparatus of claim 95 wherein said fusible material is a liquid.

104. The apparatus of claim 95 wherein said fusible material is a solid.

105. The apparatus of claim 95 wherein said fusible material is maintained at a cryogenic temperature.

106. The apparatus of claim 95 wherein said solid is a lattice.

107. The apparatus of claim 95 wherein said lattice is ice or a metal hydride.

108. The apparatus of claim 95 wherein said fusible material is provided with a proton source.

109. The apparatus of claim 95 wherein by-products of coherent fusion are removed from said containment vessel using a circulation loop.

110. The apparatus of claim 95 wherein said by-product is tritium.

111. The apparatus of claim 95 wherein said coherent fusion is stopped by selective introduction of a proton excess.

112. The apparatus of claim 95 wherein said coherent fusion is stopped by uncoupling said microwave generator.

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113. The apparatus of claim 95 wherein said vessel consists of material having a low atomic number.

114. The apparatus of claim 113 wherein said vessel is thin-walled.

115. The apparatus of claim 113 wherein said material is lithium hydride.

116. The apparatus of claim 95 wherein said apparatus for extracting usable energy consists of a metal positron trap which becomes heated as positrons are trapped.

117. The apparatus of claim 95 wherein said apparatus for extracting usable energy consists of thermally conductive mesh within said insulator for removal of heat buildup within said apparatus.

118. The apparatus of claim 95 wherein said apparatus is permeable to cosmic rays and includes an α -particle emitter to assist in initiation of coherent fusion.

119. The apparatus of claim 9, 10, 26, 27, 53, 54, 78, 79, 100 or 101 further comprising a selectively permeable membrane for adjustment of said mixture of hydrogen and deuterium.

120. The apparatus of claim 119 wherein said membrane consists of gold-coated palladium.

121. The apparatus of claim 1, 8, 10, 11, 43, 67, or 95 further comprising a neutron detector for monitoring the reaction rate.

122. The apparatus of claim 1, 8, 10, 11, 43, 67, or 95 further comprising an α -particle detector for monitoring enhanced α -decay caused by nuclear polarization.

123. A gas discharge laser comprising:

a fusion apparatus electrically connected in parallel with a variable resistance element for generating a potential between two electrodes in a chamber filled with a lasing medium; and

optical mirrors to define a laser cavity.

124. An electronic transition laser comprising: a pair of electrically excited fusion apparatuses electrically connected in series to an electronic transition laser material positioned within a laser cavity defined by optical mirrors.

125. An electronic transition laser comprising: an electrically excited fusion apparatus coupled via a filter material to an electronic transition laser material situated within a laser cavity defined by optical mirrors.

126. An electronic transition laser comprising: an electrically excited fusion apparatus coupled directly to an electronic transition laser material situated within a laser cavity defined by optical mirrors.

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127. A vibrational transition laser or maser comprising:
a fusion apparatus directly coupled to a vibrational transition laser material situated within a laser cavity defined by optical mirrors.

128. A vibrational transition laser or maser comprising:
a fusion apparatus energetically coupled through a filter material to a vibrational transition laser or maser material which is situated in a laser cavity defined by optical mirrors.

129. Apparatus for promoting chemical reaction comprising: fusion host materials immersed in a fusible material contained in a vessel provided with an inlet for introduction of chemical reactants; and
apparatus for initiating coherent fusion.

130. Apparatus for promoting chemical reaction comprising: a fusion apparatus coupled directly to chemical reactants.

131. The apparatus of claim 129 or 130 wherein said chemical reaction is synthesis of nitrogen-containing compounds.

132. Apparatus for transmutation of elements comprising fusion host materials immersed in said elements; and
apparatus for initiation of coherent fusion.

133. Apparatus for transmutation of elements comprising a fusion apparatus coupled directly to elements to be transmuted.

134. The apparatus of claim 133 wherein said elements are high atomic number radioactive isotopes.

135. A neutron spectrometer comprising:
a fusion apparatus, a conduit for conveying neutrons from the fusion apparatus to an assembly further comprising:
a neutron intensity monitor, neutron energy controller, crystal specimen indexer, scattered neutron energy analyzer, and shielding.

136. A ^3He generator comprising:
a fusion apparatus; and
a vessel for collection of ^3He generated as a byproduct of a coherent fusion process in said fusion apparatus.

137. The apparatus of claim 1 wherein said excitation apparatus generates an ion beam which impinges upon said fusible material.

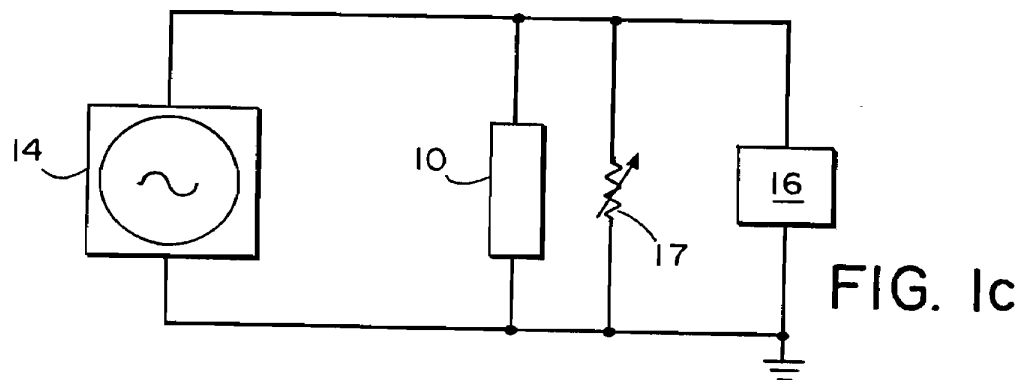
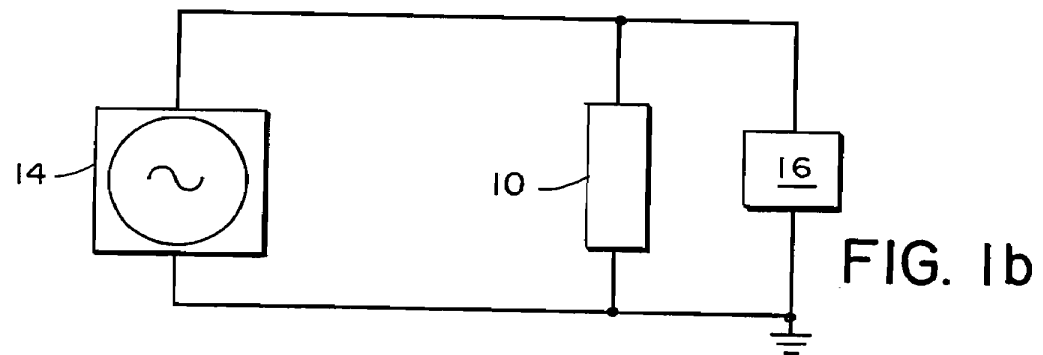
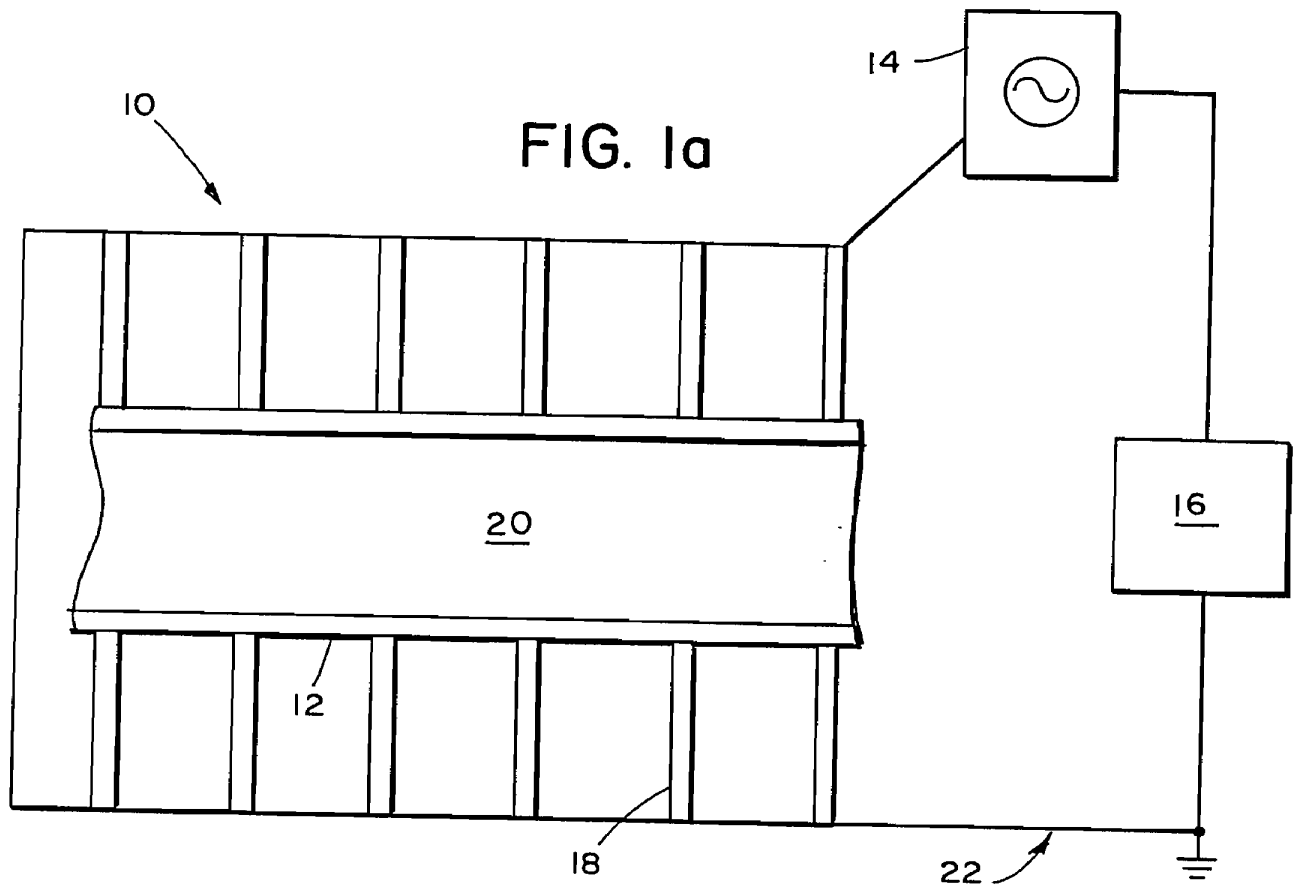
138. An amplifier comprising:

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a fusion apparatus; and
a metal plate disposed at a distance from said fusion apparatus in a vacuum.

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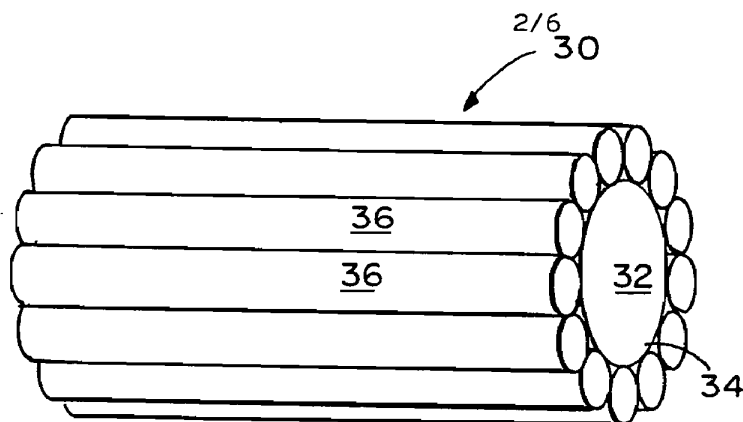


FIG. 2a

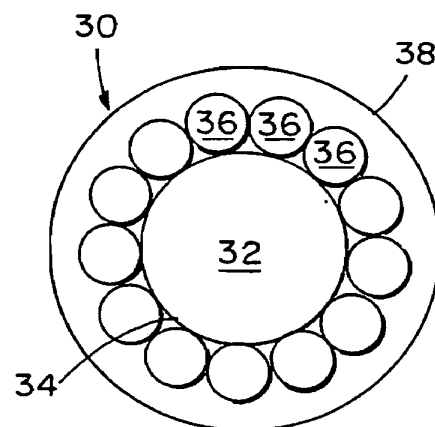


FIG. 2b

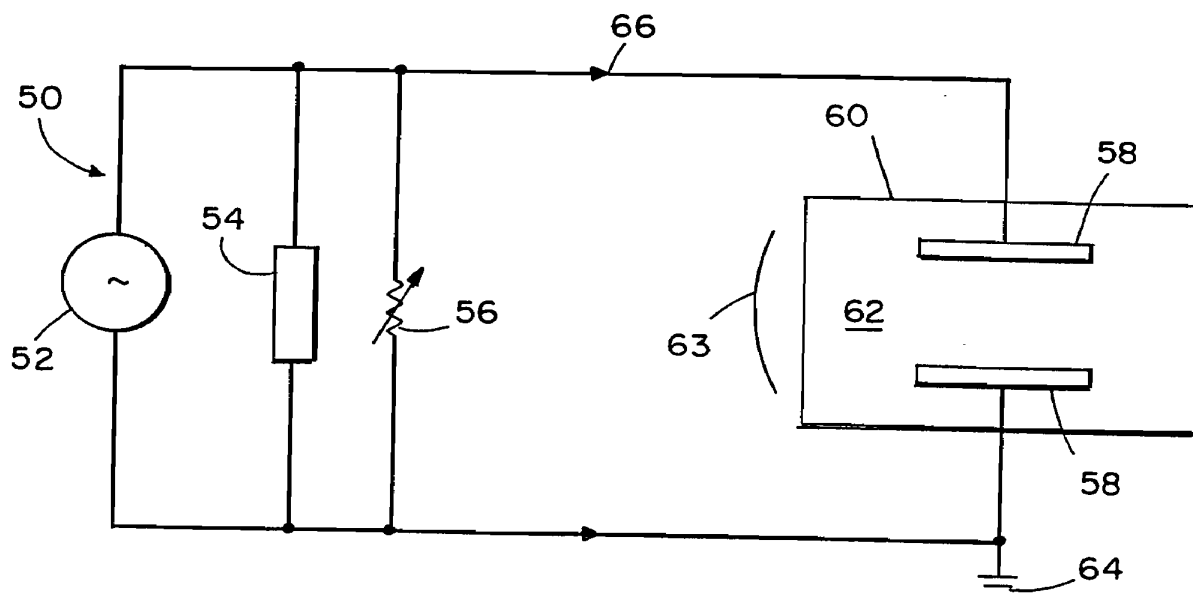
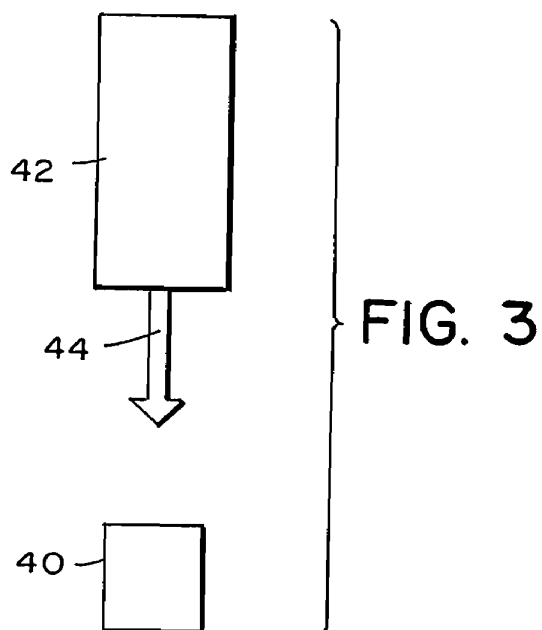


FIG. 4

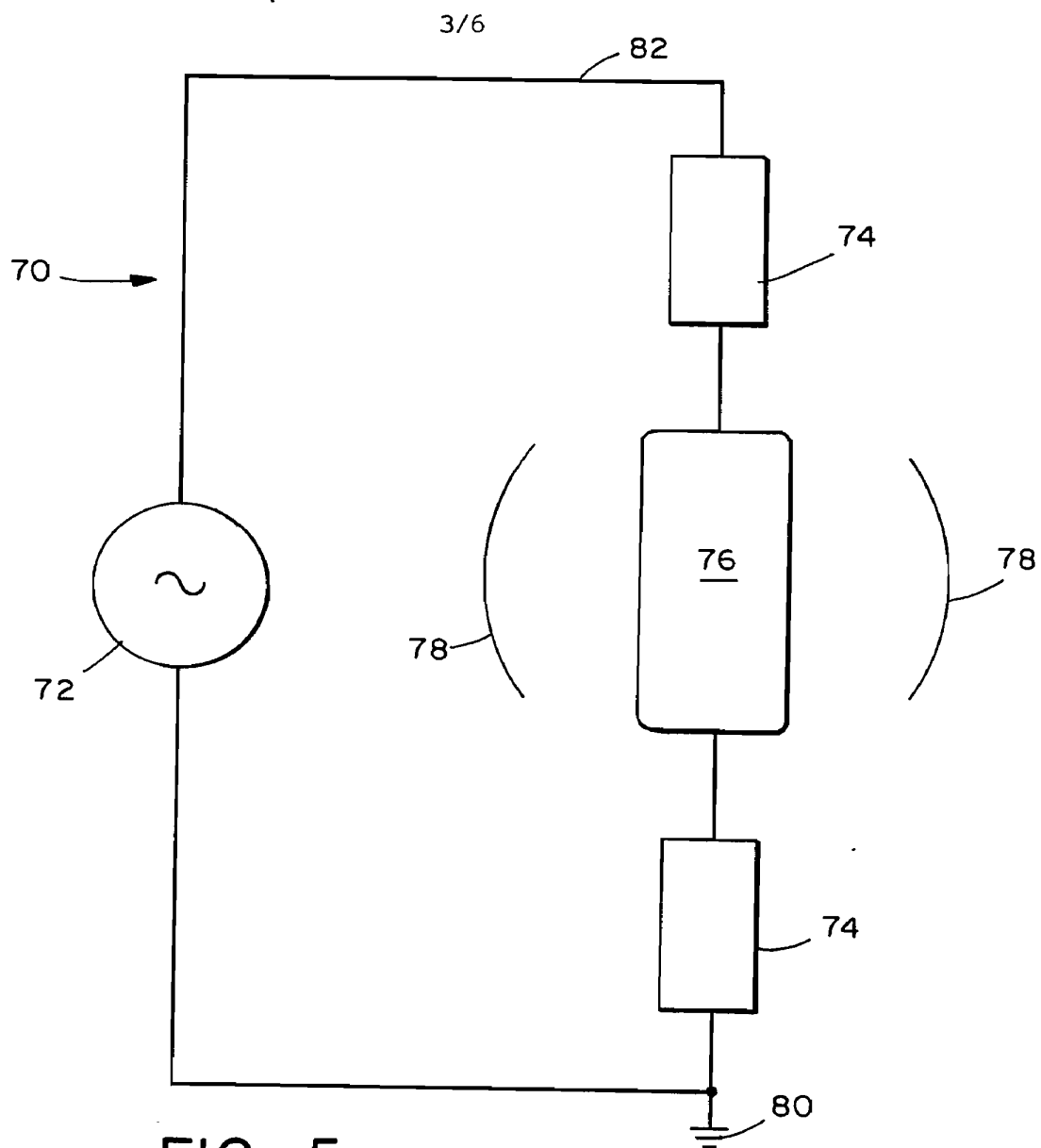


FIG. 5

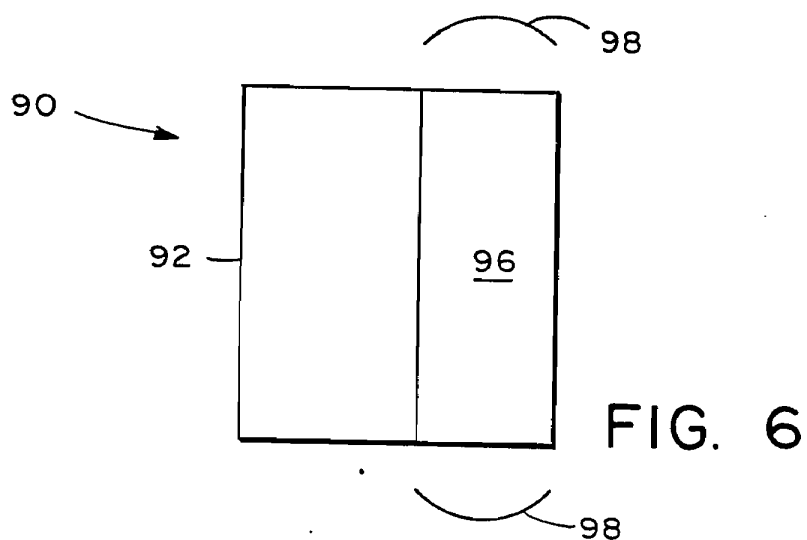


FIG. 6

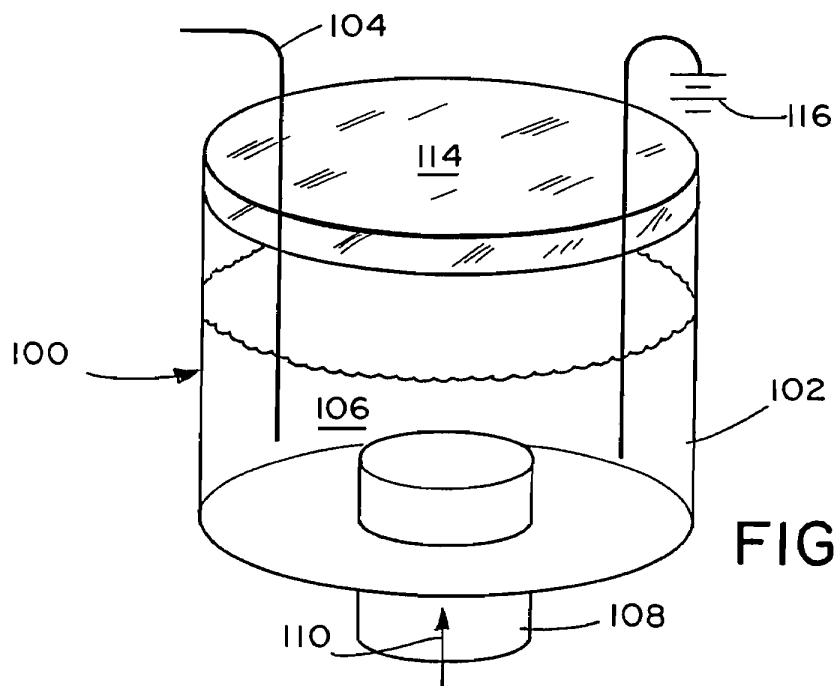


FIG. 7a

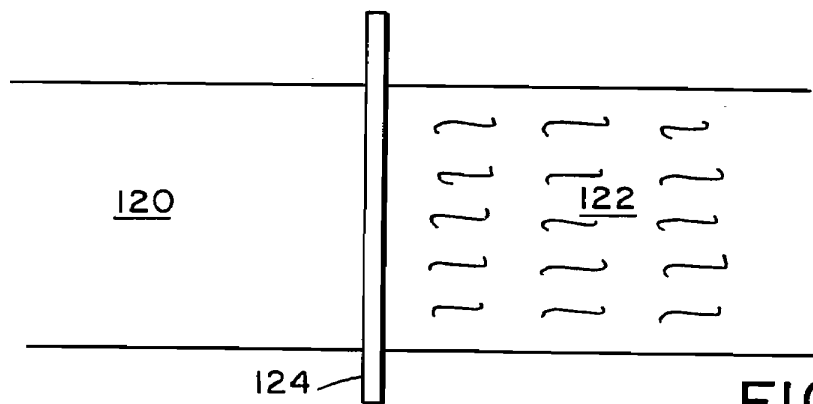


FIG. 7b

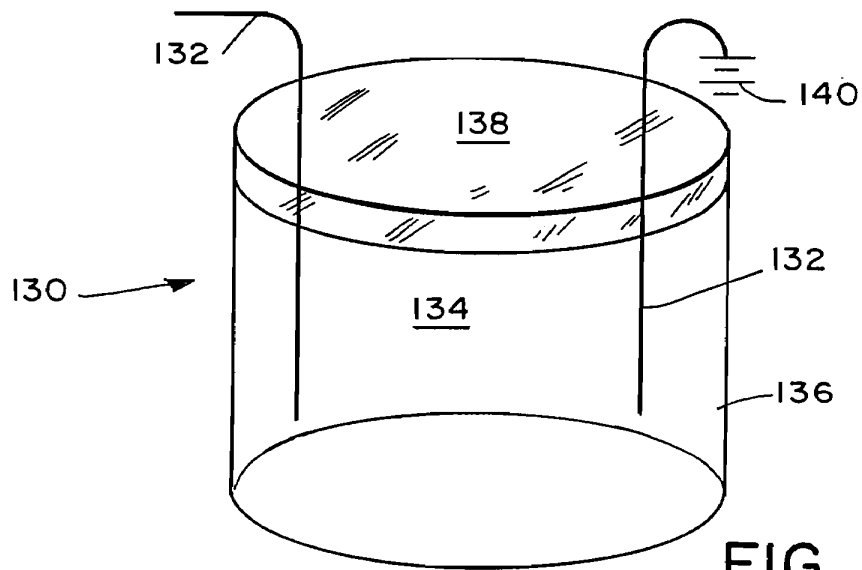


FIG. 8a

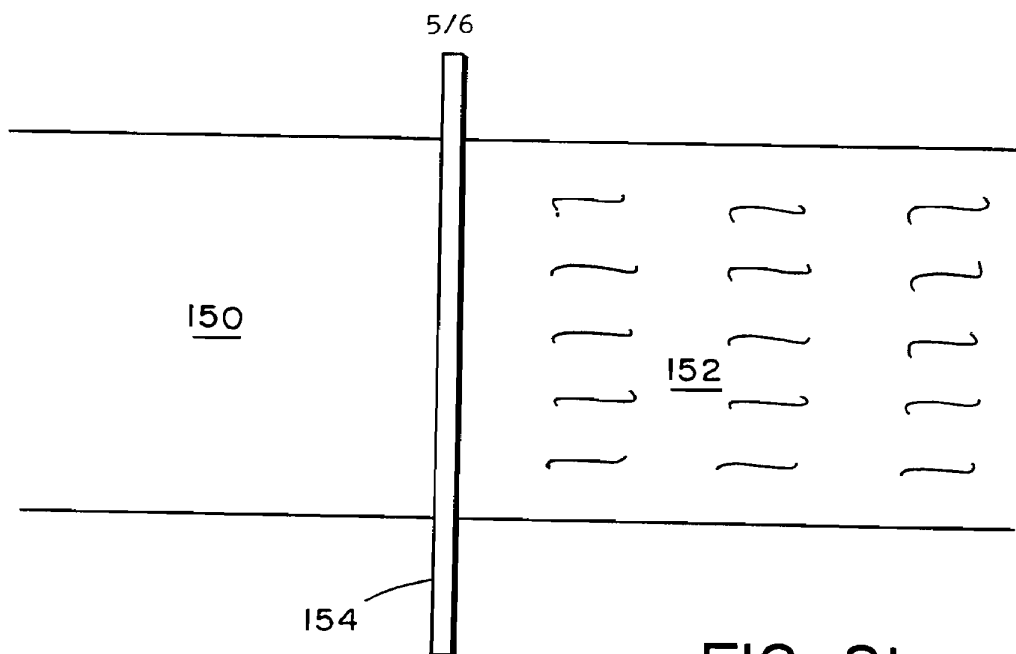


FIG. 8b

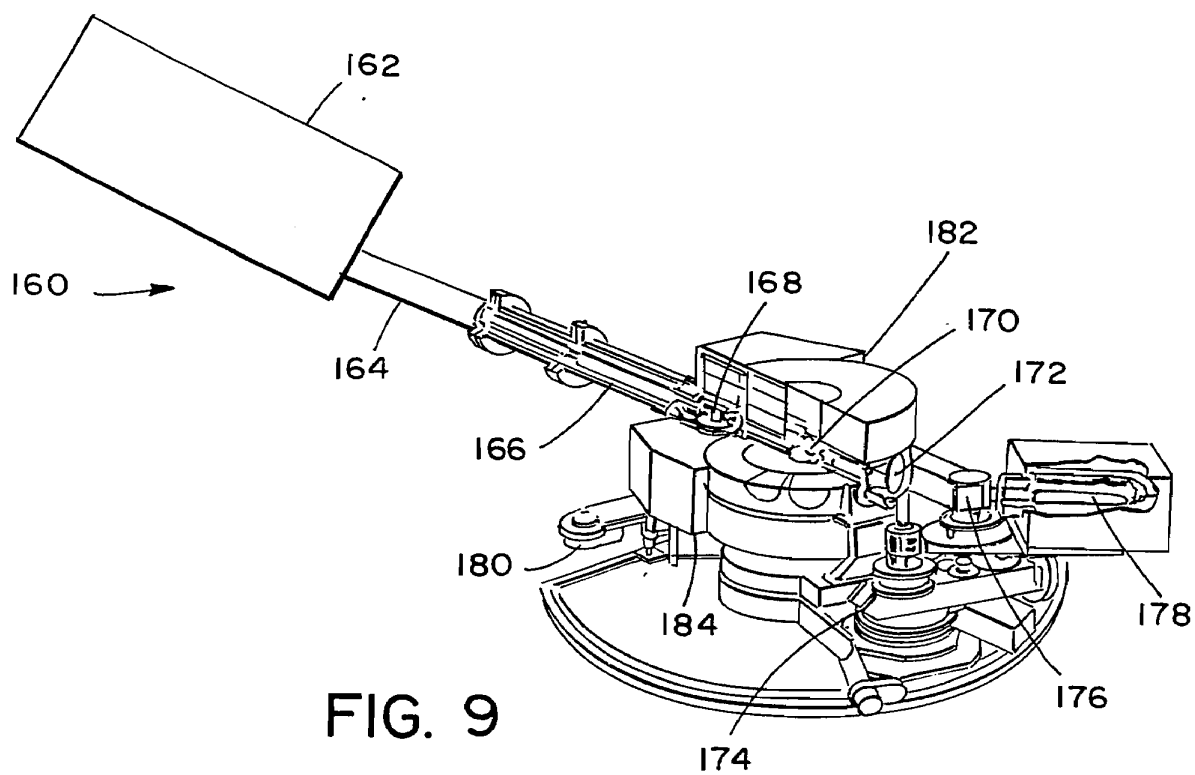


FIG. 9

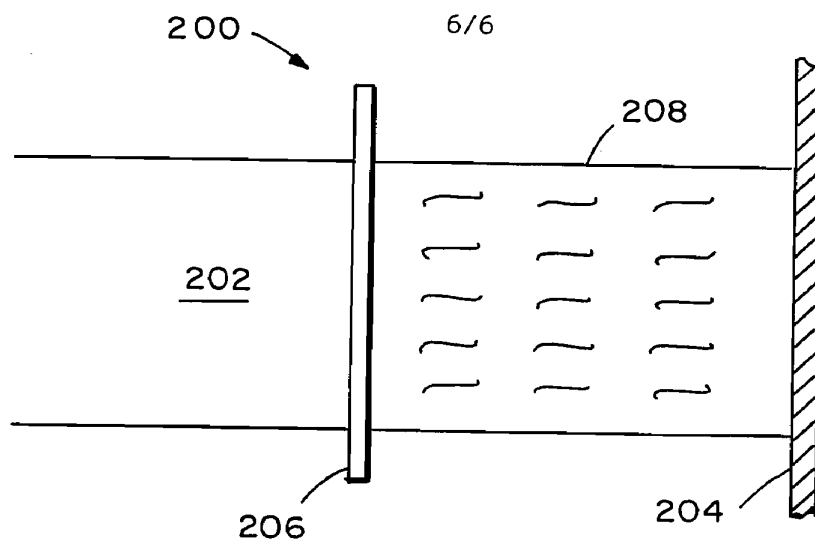


FIG. 12

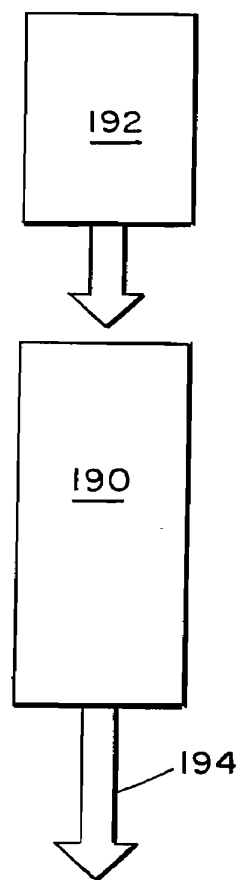


FIG. 10

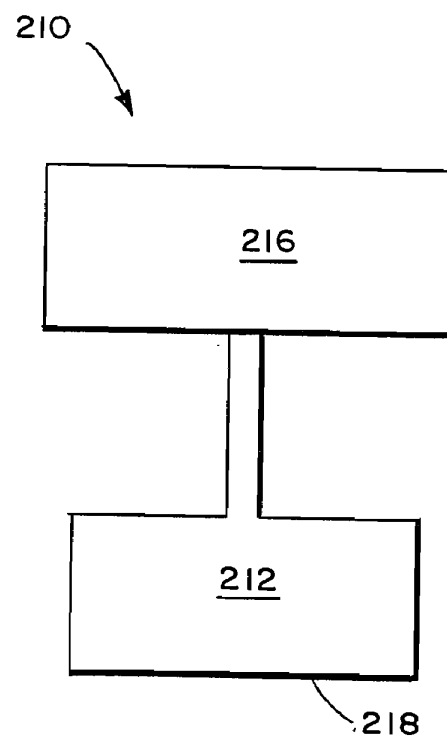


FIG. 11

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Declaration under Rule 4.17:

— as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

Published:

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(54) Title: METHODS OF GENERATING ENERGETIC PARTICLES USING NANOTUBES AND ARTICLES THEREOF

(57) Abstract: There is disclosed a method of generating energetic particles, which comprises contacting nanotubes with a source of hydrogen isotopes, such as D₂O, and applying activation energy to the nanotubes. In one embodiment, the hydrogen isotopes comprises protium, deuterium, tritium, and combinations thereof. There is also disclosed a method of transmuting matter that is based on the increased likelihood of nuclei interaction for atoms confined in the limited dimensions of a nanotube structure, which generates energetic particles sufficient to transmute matter and exposing matter to be transmuted to these particles.



WO 2007/102860 A2

METHODS OF GENERATING ENERGETIC PARTICLES USING NANOTUBES AND ARTICLES THEREOF

[001] This application claims the benefit of domestic priority under 35 USC §119(e) to U.S. Application Nos. 60/741,874, filed December 5, 2005, and 60/777,577, filed March 1, 2006, both of which are incorporated by reference herein.

[002] Disclosed herein are methods of generating energetic particles, by contacting nanotubes with hydrogen isotopes in the presence of activation energy, such as thermal, electromagnetic, or the kinetic energy of particles. Also disclosed are methods of transmuting matter by exposing such matter to the energetic particles produced according to the disclosed method.

[003] A need exists for alternative energy sources to alleviate our society's current dependence on hydrocarbon fuels without further impact to the environment. The inventors have developed multiple uses for nanotubes and devices that use such nanotubes. The present disclosure combines the unique properties of nanotubes and in one embodiment carbon nanotubes, in a novel manifestation designed to meet current and future energy needs in an environmentally friendly way.

[004] Devices powered with nanotube based nuclear power systems may substantially change the current state of power distribution. For example, nanotube based nuclear power systems may reduce, if not eliminate, the need for power distribution networks; chemical batteries; energy scavenger devices such as solar cells, windmills, hydroelectric power stations; internal combustion, chemical rocket, or turbine engines; as well as all other forms of chemical combustion for the production of power.

SUMMARY OF THE INVENTION

[005] Accordingly, there is disclosed a method of generating energetic particles, which comprises contacting nanotubes with hydrogen isotopes and applying activation energy to the nanotubes. In one embodiment, the hydrogen isotopes comprises protium, deuterium, tritium, and combinations thereof. In addition, the source of hydrogen isotopes may be in a solid, liquid, gas, plasma,

or supercritical phase. Alternatively, the source of hydrogen isotopes may be bound in a molecular structure.

[006] There is also disclosed a method of transmuting matter that comprises contacting nanotubes with a source of hydrogen isotopes, applying activation energy to the nanotubes, producing energetic particles, and contacting the matter to be transmuted with the energetic particles. As used herein, transmutable matter is matter that is transformed from one element or isotope to another element or isotope.

BRIEF DESCRIPTION OF THE DRAWINGS

[007] Fig. 1 is a schematic of a rotator type reactor for a liquid phase reaction with a He^3 detector used according to the present disclosure.

[008] Fig. 2 is a schematic of a rotator type according to Fig. 1, wherein the He^3 detector has been replaced with an array of Germanium detectors.

[009] Fig. 3 is a schematic of a reactor without a separate electrode for electrolysis of the liquid phase used according to the present disclosure.

[0010] Fig. 4 is a schematic of a reactor according to Fig. 3, further including a separate electrode for electrolysis of the liquid phase.

[0011] Fig. 5 is a schematic of a reactor for a gas phase reaction used according to the present disclosure.

[0012] Fig. 6 is a plot of the number of energetic particles generated using the reactor of Fig. 4.

DETAILED DESCRIPTION OF THE INVENTION

A. Definitions

[0013] The following terms or phrases used in the present disclosure have the meanings outlined below:

[0014] The term "fiber" or any version thereof, is defined as a high aspect ratio material. Fibers used in the present disclosure may include materials comprised of one or many different compositions.

[0015] The term “nanotube” refers to a tubular-shaped, molecular structure generally having an average diameter in the inclusive range of 25Å to 100nm. Lengths of any size may be used.

[0016] The term “carbon nanotube” or any version thereof refers to a tubular-shaped, molecular structure composed primarily of carbon atoms arranged in a hexagonal lattice (a graphene sheet) which closes upon itself to form the walls of a seamless cylindrical tube. These tubular sheets can either occur alone (single-walled) or as many nested layers (multi-walled) to form the cylindrical structure.

[0017] The phrase “environmental background radiation” refers to ionizing radiation emitted from a variety of natural and artificial sources including terrestrial sources and cosmic rays (cosmic radiation).

[0018] The term “functionalized” (or any version thereof) refers to a nanotube having an atom or group of atoms attached to the surface that may alter the properties of the nanotube, such as zeta potential.

[0019] The term “doped” carbon nanotube refers to the presence of ions or atoms, other than carbon, into the crystal structure of the rolled sheets of hexagonal carbon. Doped carbon nanotubes means at least one carbon in the hexagonal ring is replaced with a non-carbon atom.

[0020] The terms “transmuting,” “transmutation” or derivatives thereof is defined as a change of the state of the nucleus, whether its changing the number of protons or neutrons in the nucleus or changing the energy in the nucleus through capture or emission of a particle. Transmuting matter is thus defined as changing the state of the nucleus comprising the matter.

[0021] In one embodiment, there is disclosed a method of producing energetic particles from the transmutation of isotopes utilizing a nanotube structure. In this embodiment, transmutation is a change to the nuclear composition of an isotope accompanied by a release or adsorption of energy. In order to generate energy from the combination or division of stable isotopes the addition of activation energy may be required.

[0022] This activation energy may come in the form of electromagnetic stimulation either directly or indirectly which imparts momentum temperatures,

pressure or electromagnetic fields to the isotope. The initial activation energy may be in the form of a current pulse or electromagnetic radiation. Furthermore, activation energy may come in the form of energy produced from the transmutation reactions described herein, also known as a chain reaction.

[0023] In certain isotopic transmutation reactions, activation energy is the energy required to overcome the coulomb repulsion that arises when two nuclei are brought close together. The primary isotope for such a reaction is deuterium (^2H), although hydrogen (^1H), tritium (^3H), and helium three (^3He) can also be used on the way to producing energy and helium four (^4He). Included by reference is a list of isotopes which can be used for energy producing transmutation reactions and can found on 507-521 of "Modern Physics" by Hans C. Ohanian 1987, which pages are herein incorporated by reference.

[0024] In order to overcome the coulomb repulsion of the isotopes required for transmutation, activation energy may be supplied in the form of thermal, electromagnetic, or the kinetic energy of a particle. Electromagnetic energy comprises one or more sources chosen from x-rays, optical photons, α , β , or γ -rays, microwave radiation, infrared radiation, ultraviolet radiation, phonons, cosmic rays, radiation in the frequencies ranging from gigahertz to terahertz, or combinations thereof.

[0025] The activation energy may also comprise particles with kinetic energy, which are defined as any particle, such as an atom or molecule, in motion. Non-limiting embodiments include protons, neutrons, anti-protons, elemental particles, and combinations thereof. As used herein, "elemental particles" are fundamental particles that cannot be broken down to further particles. Examples of elemental particles include electrons, anti-electrons, mesons, pions, hadrons, leptons (which is a form of electron), baryons, radio isotopes, and combinations thereof.

[0026] Other particles that may be used as activation energy in the disclosed method include those mentioned by reference at pages 460-494 of "Modern Physics" by Hans C. Ohanian, which pages are herein incorporated by reference.

[0027] Similarly, the energetic particles generated by the disclosed method may comprise the same energetic particles previously described, namely neutrons, protons, electrons, beta radiation, alpha radiation, mesons, pions, hadrons, leptons, baryons, and combinations thereof. In other words, the energetic particles produced by the disclosed method may comprise the same energetic particles used to initiate the reaction.

[0028] Because energy production required for the transmutation reaction described herein uses activation energy, one can control the energy produced by controlling the amount of activation energy present or the rate at which the isotopes are being fed in the inventive process to the nanotube structure. For example, the generation of energy can be significantly reduced by freezing a nanotube/heavy water mixture, thus robbing thermal energy from the nuclear transmutation process and slowing diffusion of deuterium into the nanotubes, such as carbon nanotubes.

[0029] In one embodiment, transmuting matter may be accomplished by contacting matter with a nanotube structure, confining the matter within a dimension of the nanotube structure, and exposing the nanotube structure with the matter confined therein to activation energy.

[0030] Without being bound by any theory the methods for generation of energetic particles and transmutation reactions described herein are a manifestation, at least in part, to the nanotube structure. It is believed that when matter on the atomic scale is confined to the limited dimensions of a nanotube structure, the nucleus of the atoms comprising the matter will more likely be subject to interaction and thus transmutation of the matter. In other words, nanoscale confinement increases the probabilities that nuclei of matter will interact. Similar theories have been described as screening in a one-dimensional Bose gas, a description of which can be found in the article by N.M. Bogolyubov et al., *Complete Screening in a One-Dimensional Bose Gas*, Zapiski Nauchnykh Seminarov Leningradskogo Otdeleniya Matematicheskogo Instituta im. V.A. Steklova AN SSSR, Vol. 150 pp. 3-6, 1986.

[0031] Thus, in one embodiment, it is believed that with a high density electron plasma inside the confined system of a carbon nanotube when a current,

such as in the form of a pulse, is applied to the carbon nanotube, and in the presence of deuterium, coulomb repulsion may be reduced or eliminated. Electrons may be in very close proximity to the nuclei, thus on average canceling out the coulomb repulsion between deuterium isotopes. This in turn should decrease the required activation energy for transmutation.

[0032] Any nanoscaled structure having a hollow interior that assists or enables nanoscale confinement, and that is capable of withstanding the internal conditions associated with the disclosed method, can be used in the disclosed process.

[0033] In one embodiment, the nanotubes comprises carbon and its allotropes. For example, the carbon nanotube used according to the present disclosure may comprise a multi-walled carbon nanotube having a length ranging from 500 μ m to 10cm, such as from 2mm to 10mm. Nanotube structures according to the present disclosure may have an inside diameter ranging up to 100nm, such as from 25 Å to 100nm.

[0034] The nanotube material may also comprise a non-carbon material, such as an insulating, metallic, or semiconducting material, or combinations of such materials.

[0035] It is to be appreciated that the hydrogen isotopes may be located within the interior of a nanotube, the space between the walls of a multi-walled nanotube (when used), inside at least one loop formed by one or more nanotubes, or combinations thereof.

[0036] In one embodiment, the nanotubes may be aligned end to end, parallel, or in any combination thereof. In addition, or alternatively, the nanotubes may be fully or partially coated or doped by least one atomic or molecular layer of an inorganic material.

[0037] In certain embodiments, the methods of transmuting matter may be enhanced when the nanotube structure catalytically interacts with the matter confined therein. This may be done by either choosing a particular nanotube, such as carbon, or by doping or coating the nanotube with a molecule that can alter the amount or type of activation energy needed to initiate the disclosed reactions.

[0038] As used herein, "catalyst" any word derived therefrom, is defined as a substance that changes the activation energy. In one embodiment, changing the activation energy is defined as lowering the energy required for transmutation reaction(s) to occur.

[0039] When the nanotube structure further acts as a catalyst, it may do so as an integrator, taking many low energy photons, phonons or particles and additively delivering their energy to the transmutation nuclei. The previously mentioned forms of activation energy may also be used in such a process.

[0040] In some cases, activation energy may result from the sum of multiple forms of energy, such as x-rays nanotube capture coincident with electron nuclear scattering to drive the transmutation reaction, such as the transmutation of deuterium into ^3He and neutrons.

[0041] In certain embodiments, it is possible to produce a chain reaction by loading hydrogen isotopes within the nanotube so that energy released from one transmutation event will drive more transmutation events.

[0042] As stated, method of transmuting matter may lead to the generation of energy, from the release of energetic particles. In non-limiting embodiments, the energy generated from the disclosed method may comprise neutrons tritons, helium isotopes and protons with kinetic energy.

[0043] The nanotube structure disclosed herein may comprise single walled, double walled or multi-walled nanotubes or combinations thereof. The nanotubes may have a known morphology, such as those described in Applicants co-pending applications, including U.S. Patent Application 11/111,736, filed April 22, 2005, U.S. Patent Application No. 10/794,056, filed March 8, 2004 and U.S. Patent Application No. 11/514,814, filed September 1, 2006, all of which are herein incorporated by reference.

[0044] Some of the above described shapes are more particularly defined in M.S. Dresselhaus, G. Dresselhaus, and P. Avouris, eds. Carbon Nanotubes: Synthesis, Structure, Properties, and Applications, *Topics in Applied Physics*. 80. 2000, Springer-Verlag; and "A Chemical Route to Carbon Nanoscrolls, Lisa M. Viculis, Julia J. Mack, and Richard B. Kaner; *Science*, 28 February 2003; 299, both of which are herein incorporated by reference.

[0045] When nanotube structures having the foregoing morphologies are employed, the confinement dimension, defined as the dimension in which the matter undergoing transmutation is confined, is chosen from the interior of a nanotube, the space between the walls of a multi-walled nanotube, inside at least one loop formed by one or more nanotubes, or combinations thereof.

[0046] As previously stated, the method according to the present disclosure typically uses an activation energy to assist in transmutation. Non-limiting examples of such activation energy includes microwave radiation, infrared radiation, thermal energy, phonons, optical photons, ultraviolet radiation, x-rays, γ -rays, α -radiation, β -radiation, and cosmic rays.

[0047] It is understood that the nanotube structure may comprise a network of nanotubes which are optionally in a magnetic, electric, or otherwise electromagnetic field. In one non-limiting embodiment, the magnetic, electric, or electromagnetic field can be supplied by the nanotube structure itself.

[0048] In addition, the method may further include applying an alternating current direct current or current pulses to the nanotube structure or combinations thereof.

[0049] The nanotube structure disclosed herein may have a epitaxial layers of metals or alloys.

[0050] The composition of the nanotube is not known to be critical to the methods described herein. Without being bound by theory, it appears that the confinement of the species within the nanotube may be responsible for the effects that are disclosed herein, rather than some interaction of the carbon in the nanotubes used in the disclosed embodiment and the species that was energized by the confinement, deuterium. For this reason, while the nanotubes describe herein are specifically described as carbon, more generally, they can comprise ceramic (including glasses), metallic (and their oxides), organic, and combinations of such materials.

[0051] The morphology (geometric configuration) of the nanotubes, other than providing confinement in a dimension for the species being energized, is not known to be critical. In one embodiment, there is disclosed a multi-walled, carbon nanotube. The nanotube structure disclosed herein may have single or

multiple atomic or molecular layers forming a shell or coating on the nanotubes described herein. In addition to such coatings, the nanotube structure may be doped by least one atomic or molecular layer of an inorganic or organic material.

[0052] A description of coatings for nanotubes, as well as methods of coating nanotubes, are described in applicants co-pending application, which were previously incorporated by reference, i.e., U.S. Patent Application 11/111,736, filed April 22, 2005, U.S. Patent Application No. 10/794,056, filed March 8, 2004 and U.S. Patent Application No. 11/514,814, filed September 1, 2006.

[0053] The method described herein may further comprise functionalizing the carbon nanotubes with at least one organic group. Functionalization is generally performed by modifying the surface of carbon nanotubes using chemical techniques, including wet chemistry or vapor, gas or plasma chemistry, and microwave assisted chemical techniques, and utilizing surface chemistry to bond materials to the surface of the carbon nanotubes. These methods are used to "activate" the carbon nanotube, which is defined as breaking at least one C-C or C-heteroatom bond, thereby providing a surface for attaching a molecule or cluster thereto.

[0054] Functionalized carbon nanotubes may comprise chemical groups, such as carboxyl groups, attached to the surface, such as the outer sidewalls, of the carbon nanotube. Further, the nanotube functionalization can occur through a multi-step procedure where functional groups are sequentially added to the nanotube to arrive at a specific, desired functionalized nanotube.

[0055] Unlike functionalized carbon nanotubes, coated carbon nanotubes are covered with a layer of material and/or one or many particles which, unlike a functional group, is not necessarily chemically bonded to the nanotube, and which covers a surface area of the nanotube.

[0056] Carbon nanotubes used herein may also be doped with constituents to assist in the disclosed process. As stated, a "doped" carbon nanotube refers to the presence of ions or atoms, other than carbon, into the crystal structure of the rolled sheets of hexagonal carbon. Doped carbon

nanotubes means at least one carbon in the hexagonal ring is replaced with a non-carbon atom.

[0057] Also disclosed is a method of transmuting matter that comprises contacting nanotubes with a source of hydrogen isotopes, applying activation energy to the nanotubes, producing energetic particles, and contacting the matter to be transmuted with the energetic particles.

[0058] A fraction of the energy produced from transmutation in the form of radiation may be used directly to drive second generation transmutation reactions. This method can be used to continually generate power to the levels required for consumption.

[0059] In one embodiment, the method described herein may be used to transmute isotopes having a long half-life and considered to be radioactive pollutants into isotopes with a shorter half-life. This may be accomplished via neutron capture. In this embodiment, it may be desirable to feed the nanotube with deuterium since many neutrons packed closely together in the carbon nanotubes can be captured by the target isotope. The abundance of neutrons in the nucleus will drive transmutation reactions, this reducing the half-life of a radioactive isotope from hundreds or thousands of years to milliseconds.

[0060] In another embodiment, the transmutation of deuterium into ^3He and neutrons may be performed by contacting carbon nanotubes with a deuterium gas and activation energy. In this embodiment, the deuterium is kept in high concentration by a confinement vessel that surrounds the element components, e.g., the deuterium gas, the carbon nanotubes, and attached electrodes. In addition, the carbon nanotubes should be bundled to make electrical contact with the electrodes at either end of the bundle. Wires are attached to the electrode and feed the carbon nanotubes with activation energy from a circuit that produces a 400V pulse for 10ns. A schematic of this embodiment is shown in Fig. 5.

[0061] The present disclosure is further illustrated by the following non-limiting examples, which are intended to be purely exemplary of the disclosure.

EXAMPLES

Example 1. Production of Energetic Particles Using Treated Carbon Nanotubes

a) Production of Carbon Nanotube Material

[0062] 5g of carbon nanotubes were mixed with 250 ml of reagent grade nitric acid at room temperature. The carbon nanotubes were multi-walled, with diameters ranging from 10nm to 50nm and lengths ranging from 100 nm to 100um. After 20 minutes, the carbon nanotubes were removed from the nitric acid and washed with water three times. The carbon nanotubes were dried in an oven set above room temperature to remove water. From that batch, 100 mg of the carbon nanotubes were combined with 35-40 ml of 99.9% pure D₂O in a 50 ml glass beaker (Sample A). The D₂O was taken from a new 250 gram sample that was purchased from Sigma Aldrich (Part number 151882-250G, Batch number 08410KC).

b) Measurements on Carbon Nanotube Material

[0063] Various energetic particles emitted from Sample A were measured in the following manner:

[0064] Sample A was covered with clear plastic wrap to minimize evaporation of the D₂O and water absorption into the hygroscopic D₂O. It was then placed in a rotatable sample holder, which was held at a 45 degree angle relative to the floor and rotated at about 1 rpm during measurement so as to keep the surface carbon nanotubes at least partially wet. A schematic of this rotating sample holder is shown in Fig. 1.

[0065] Energy above background was measured using a ³He Neutron detector and a NaI (sodium iodide) gamma/x-ray detector. Background measurements were made with no sample present. Sample A was initially measured in a dark room. The measurement was repeated with the sample irradiated by a UV filtered halogen light. A second sample (B), identical in composition and morphology to sample A was prepared. Sample B was irradiated separately with (a) a UV filtered halogen light and (b) a red laser.

[0066] While all samples, including that measured in the dark room, showed a positive bias above background, enhanced signal was noticed when a light source was used, with the strongest response occurring for the UV filtered halogen light.

[0067] This example shows that by combining treated carbon nanotubes with D₂O, energetic particles were produced.

Example 2. Production of Energetic Particles Using Untreated Carbon Nanotubes

a) Production of Carbon Nanotube Material

[0068] This example was substantially similar to Ex. 1, with the exception that untreated multi-walled carbon nanotubes were used in this example. The carbon nanotubes had diameters ranging from 10nm to 50nm and lengths ranging from 100 nm to 100um. About 100 mg of the carbon nanotubes were combined with 35-40 ml of 99.9% pure D₂O in a 50 ml glass beaker.

b) Measurements on Carbon Nanotube Material

[0069] Energetic particles emitted from the sample made according to this invention were measured in the following manner:

[0070] As in Example 1, the sample according to this example was covered with clear plastic wrap to minimize evaporation of the D₂O and water absorption into the hygroscopic D₂O. It was then placed in a rotatable sample holder, which was held at a 45 degree angle relative to the floor and rotated at about 1 rpm during measurement so as to keep the surface carbon nanotubes at least partially wet.

[0071] A schematic of the set-up used in this Example is shown in Fig. 2, which is similar to Fig. 1, with the ³He detector being replaced by an array of Germanium detectors. In particular, prior to the application of the activation energy, two arrays of Germanium neutron detectors, placed on either side of the apparatus, were calibrated to determine the background rate of neutrons at the site of the experiment. The detectors were state of the art neutron detectors that

were the property of the Lawrence Livermore National Laboratories and the manner in which the detectors operated was proprietary to their owners.

[0072] Background measurements were made with no sample present. The measurement was made while the sample was irradiated by a UV filtered halogen light. While all measurements including background showed a positive bias above background, enhanced signal was noticed when the UV filtered halogen light was applied.

[0073] This example shows that by combining untreated carbon nanotubes with D₂O, while applying activation energy, energetic particles were produced.

Example 3. Production of Energetic Particles Via Transmutation in a Liquid Phase - Without An Electrolysis Electrode

[0074] In this example the nanotubes were commercially pure carbon nanotubes obtained from NanoTechLabs (NanoTechLabs Inc., 409 W. Maple St., Yadkinville, NC 27055). They had a length of approximately 3mm, with a 6 member ring structure and were straight in orientation. The carbon nanotubes were substantially defect free and were not treated prior to use in the device.

[0075] A bundle of aligned carbon nanotubes containing approximately 1,000 individual nanotube was connected to stainless steel electrodes at each end of the bundle. The carbon nanotube electrode system was measured to have approximately 200Ω of resistance. One nanotube electrode was connected through a capacitor to ground and to a 19.5Ω resistor connected to the high voltage supply. See Fig. 3. The other nanotube electrode was connected through a 30ns rise time transistor to ground. The gate on the transistor was connected to a pulse generator.

[0076] The carbon nanotube electrode system was submerged in 2 grams of liquid D₂O in a ceramic reactor boat at room temperature and pressure. A voltage was applied to the carbon nanotubes as a 200 Volt spike for a duration in the range of from 200 nanoseconds at a repetition rate of approximately 10KHz.

[0077] A signal generator delivered a 150ns wide pulse at 9V to the transistor to trigger the discharge of the capacitor through the deuterium loaded

carbon nanotubes. Neutron bursts were produced for a 2hr time period before the stainless steel electrodes corroded due to electro corrosion and no longer made contact with the carbon nanotubes. The data acquisition system recorded data above background for this time period.

[0078] Prior to the application of the voltage two arrays of Germanium neutron detectors, placed on either side of the apparatus, were calibrated to determine the background rate of neutrons at the site of the experiment. The detectors were state of the art neutron detectors that were the property of the Lawrence Livermore National Laboratories and the manner in which the detectors operated was proprietary to their owners.

[0079] Prior to the application of voltage, the detectors intermittently detected neutron with no observed periodicity of detections. This was comparable to background radiation. After the voltage was applied to the carbon nanotube again the detectors detected neutrons intermittently. The neutrons were detected in short duration bursts and as a low level steady stream above background with the detection event being from four to 100 times the magnitude of the background detections. When the application of the voltage was discontinued the detections were again characteristic in magnitude of those at background levels and no periodicity of the bursts was observed. The kinetic energy of the detected neutron could not be measured with the equipment used.

[0080] The experimental apparatus had no provision for measuring any heat generated during the operation of the device. Nor was there any provision for testing the composition of gases that may have been created during the process.

Example 4. Production of Energetic Particles Via Transmutation in a Liquid Phase - With An Electrolysis Electrode

[0081] In this example the nanotubes were commercially pure carbon nanotubes obtained from NanoTechLabs (NanoTechLabs Inc., 409 W. Maple St., Yadkinville, NC 27055). They had a length of approximately 6mm, with a 6

member ring structure and were straight in orientation. The carbon nanotubes were substantially defect free and were not treated prior to use in the device.

[0082] A bundle of aligned carbon nanotubes containing approximately 1,000 individual nanotube was connected to platinum electrodes at each end of the bundle. The carbon nanotube electrode system was measured to have approximately 8Ω of resistance. One nanotube electrode was connected through a capacitor to ground. The other nanotube electrode was connected through a transistor to ground. A third electrolysis electrode was held in close proximity to the center of the carbon nanotube bundle and was connected to a 490V 5mA power supply through a $6K\Omega$ resistor. A schematic and description of this set-up is shown in Fig. 4.

[0083] The carbon nanotube electrode system was submerged in 2 grams of liquid D_2O in a ceramic reactor boat at room temperature and pressure. A voltage was applied to the carbon nanotubes as a 490 Volt spike for a duration in the range of from 10 to 100 nanoseconds at a repetition rate of approximately 730 Hz. During the millisecond the capacitor was charging, the charging current was also used to perform electrolysis of the D_2O to produce D_2 gas at the nanotube surface. Electrolysis was performed to increase diffusion of D_2 into the carbon nanotube. A signal generator delivered a 150ns wide pulse at 9V to the transistor to trigger the discharge of the capacitor through the deuterium loaded carbon nanotubes. Neutron bursts were produced and recorded by a data acquisition system that were not present in the background.

[0084] A plot of the number of energetic particles generated according to this example is shown in Fig. 6.

[0085] Prior to the application of the voltage two arrays of Germanium neutron detectors, placed on either side of the apparatus, were calibrated to determine the background rate of neutrons at the site of the experiment. The detectors were state of the art neutron detectors that were the property of the Lawrence Livermore National Laboratories and the manner in which the detectors operated was proprietary to their owners.

[0086] Prior to the application of voltage, the detectors intermittently detected neutron with no observed periodicity of detections. This was

comparable to background radiation. After the voltage was applied to the carbon nanotube again the detectors detected neutrons intermittently. As shown in Fig. 6, the neutrons were detected in short duration bursts with the detection event being from four to ten thousand times the magnitude of the background detections. In addition, over time a periodicity of the bursts was observed, the frequency of which was approximately 10 minutes. When the application of the voltage was discontinued the detections were again characteristic in magnitude of those at background levels and no periodicity of the bursts was observed. The kinetic energy of the detected neutron could not be measured with the equipment used.

[0087] The experimental apparatus had no provision for measuring any heat generated during the operation of the device. Nor was there any provision for testing the composition of gases that may have been created during the process. The composition of the liquid remaining after the experiment was determined and the amount of heavy water in the sample had decreased.

[0088] The data generated from this example was statistically analyzed via a Hurst analysis to determine the statistical significance of the results. A Hurst analysis is a correlated analysis of random and non-random occurrences of events yielding a figure of merit. A figure of merit centered around 0.5 indicates random data. A figure of merit approaching 1.0 indicates positive correlation. A figure of merit approaching zero indicates anti-correlation. Data according to this example approached 0.9 indicating high positive correlation. In other words, the statistical analysis of the data from this example provides strong evidence of non-random signal.

[0089] Unless otherwise indicated, all numbers expressing quantities of ingredients, reaction conditions, and so forth used in the specification and claims are to be understood as being modified in all instances by the term "about." Accordingly, unless indicated to the contrary, the numerical parameters set forth in the following specification and attached claims are approximations that may vary depending upon the desired properties sought to be obtained by the present invention.

[0090] Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with the true scope of the invention being indicated by the following claims.

What Is Claimed Is:

1. A method of generating energetic particles, said method comprising contacting nanotubes with hydrogen isotopes, and applying activation energy to said nanotubes.
2. The method of claim 1, wherein said hydrogen isotopes comprises protium, deuterium, tritium, and combinations thereof.
3. The method of claim 1, wherein said hydrogen isotopes are provided from a source that is in a solid, liquid, gas, plasma, or supercritical phase.
4. The method of claim 1, wherein said hydrogen isotopes are provided from a source that are bound in a molecular structure.
5. The method of claim 1, wherein hydrogen isotopes are provided via D₂O.
6. The method of claim 1, wherein said activation energy comprises thermal, electromagnetic, or the kinetic energy of a particle.
7. The method of claim 6, wherein said electromagnetic energy comprises one or more sources chosen from x-rays, optical photons, γ -rays, microwave radiation, infrared radiation, ultraviolet radiation, phonons, radiation in the frequencies ranging from gigahertz to terahertz, or combinations thereof.
8. The method of claim 6, wherein said particle containing kinetic energy is chosen from neutrons, protons, electrons, beta radiation, alpha radiation, mesons, pions, hadrons, leptons, baryons, and combinations thereof.
9. The method of claim 1, wherein said energetic particles comprise neutrons, protons, electrons, beta radiation, alpha radiation, mesons, pions, hadrons, leptons, baryons, and combinations thereof.
10. The method of claim 1, wherein said nanotubes comprise carbon nanotubes.
11. The method of claim 1, wherein said nanotube is a multi-walled carbon nanotube.
12. The method of claim 1, wherein said nanotube is a multi-walled carbon nanotube has a length ranging from 500 μ m to 10cm.

13. The method of claim 1, wherein said nanotube is a multi-walled carbon nanotube having a length ranging from 2mm to 10mm.

14. The method of claim 1, wherein said hydrogen isotopes are located within the interior of a nanotube, the space between the walls of a multi-walled nanotube, inside at least one loop formed by one or more nanotubes, or combinations thereof.

15. The method of claim 1, further comprising forming a bundle of carbon nanotubes and providing activation energy in the form of electrical energy, to the bundle.

16. The method of claim 13, wherein said electrical energy is in the form of an electrical pulse.

17. The method of claim 1, wherein said nanotubes are aligned end to end, parallel, or in any combination thereof.

18. The method of claim 1, wherein said nanotube structure has an inside diameter ranging up to 100nm.

19. The method of claim 1, wherein the said nanotube is comprised of insulating, metallic, or semiconducting materials and combinations of such materials.

20. The method of claim 1, wherein said nanotubes consist essentially of carbon and its allotropes.

21. The method of claim 1, further comprising at least partially coating or doping least one atomic or molecular layer of an inorganic material prior to applying said activation energy.

22. The method of claim 1, wherein said activation energy comprises environmental background radiation.

23. The method of claim 22, wherein said environmental background radiation comprises cosmic rays.

24. A method of transmuting matter, said method comprising contacting nanotubes with a source of hydrogen isotopes, applying activation energy to said nanotubes, producing energetic particles, and contacting the matter to be transmuted with said energetic particles.

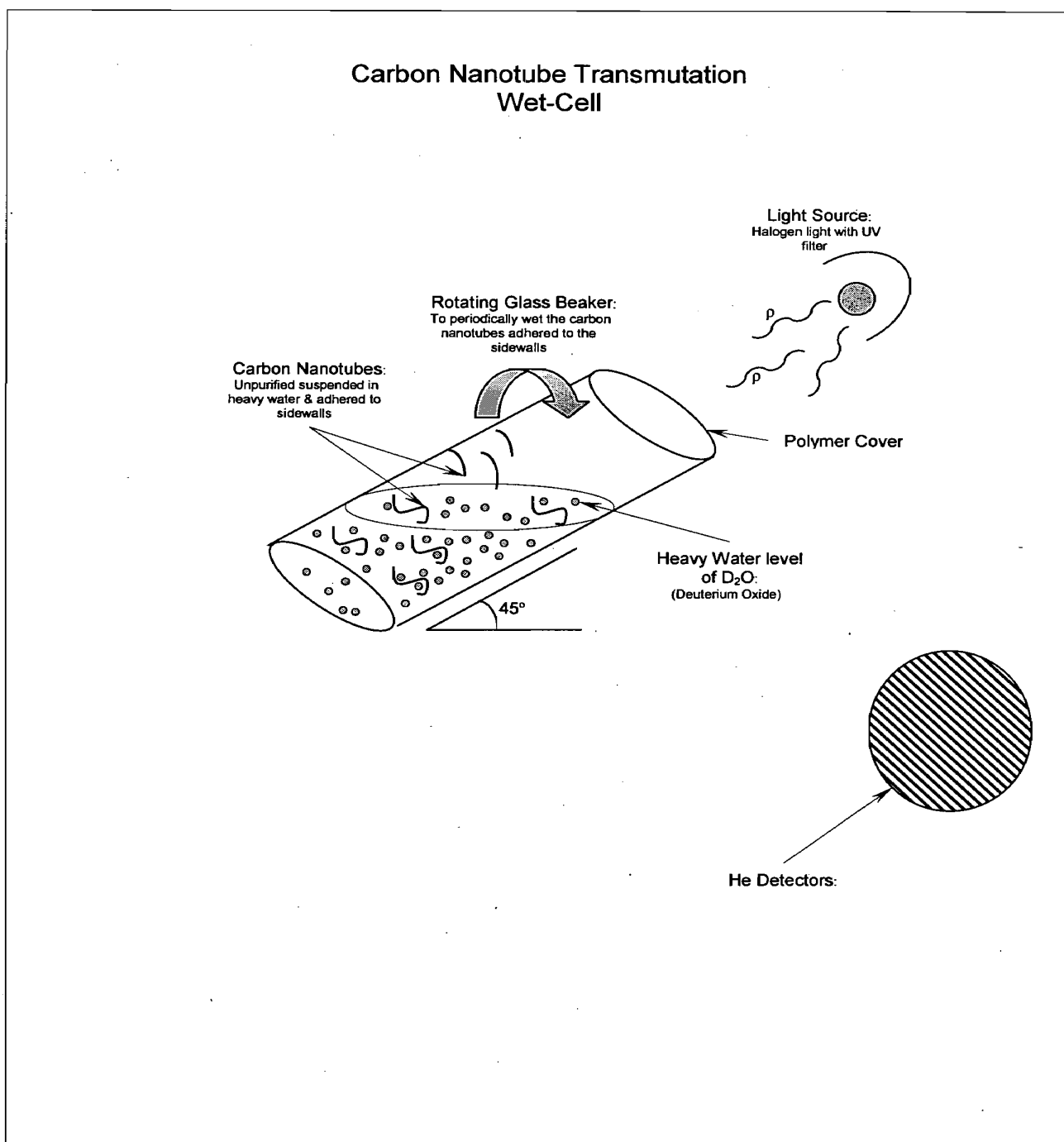


Figure 1

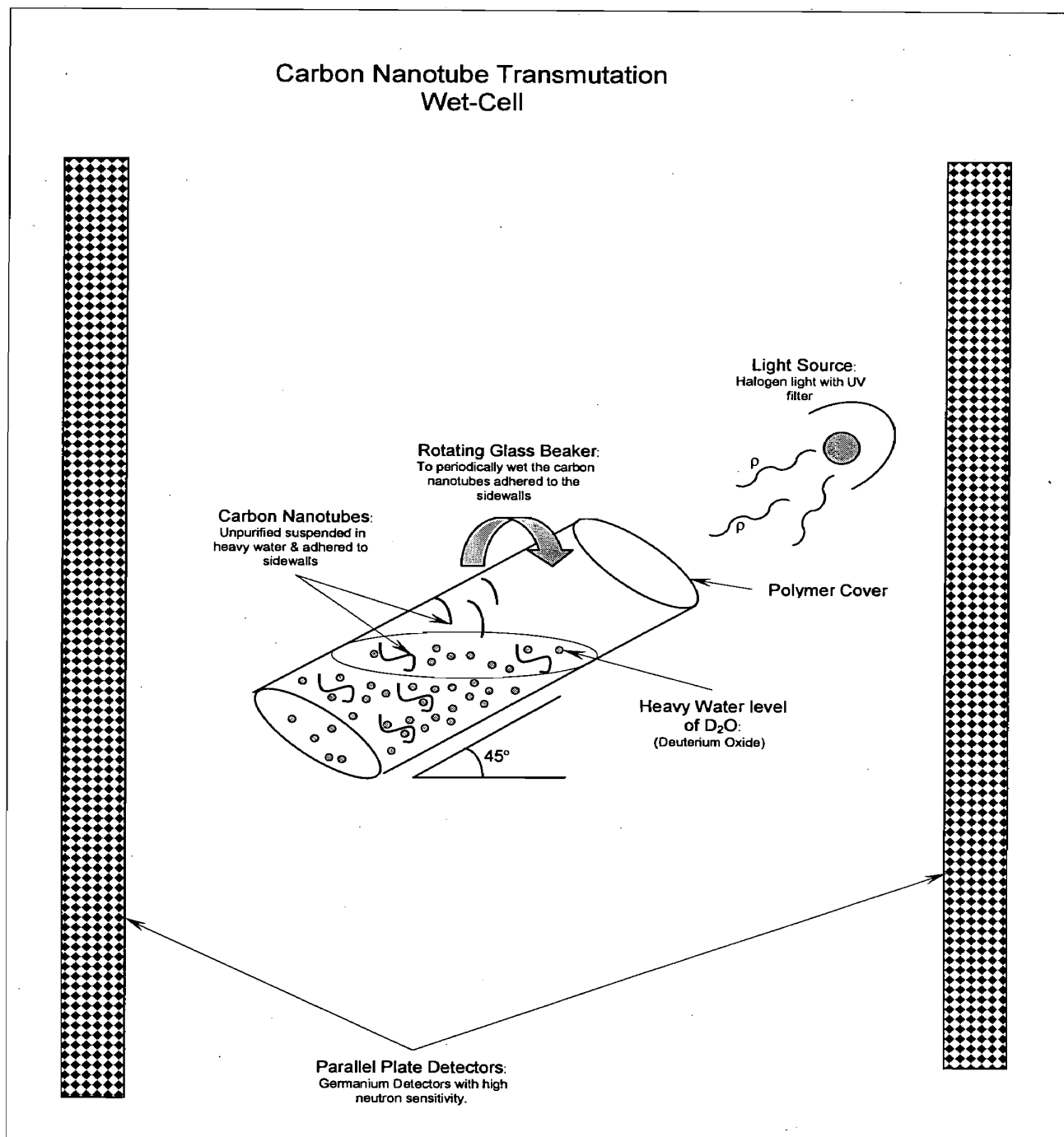


Figure 2

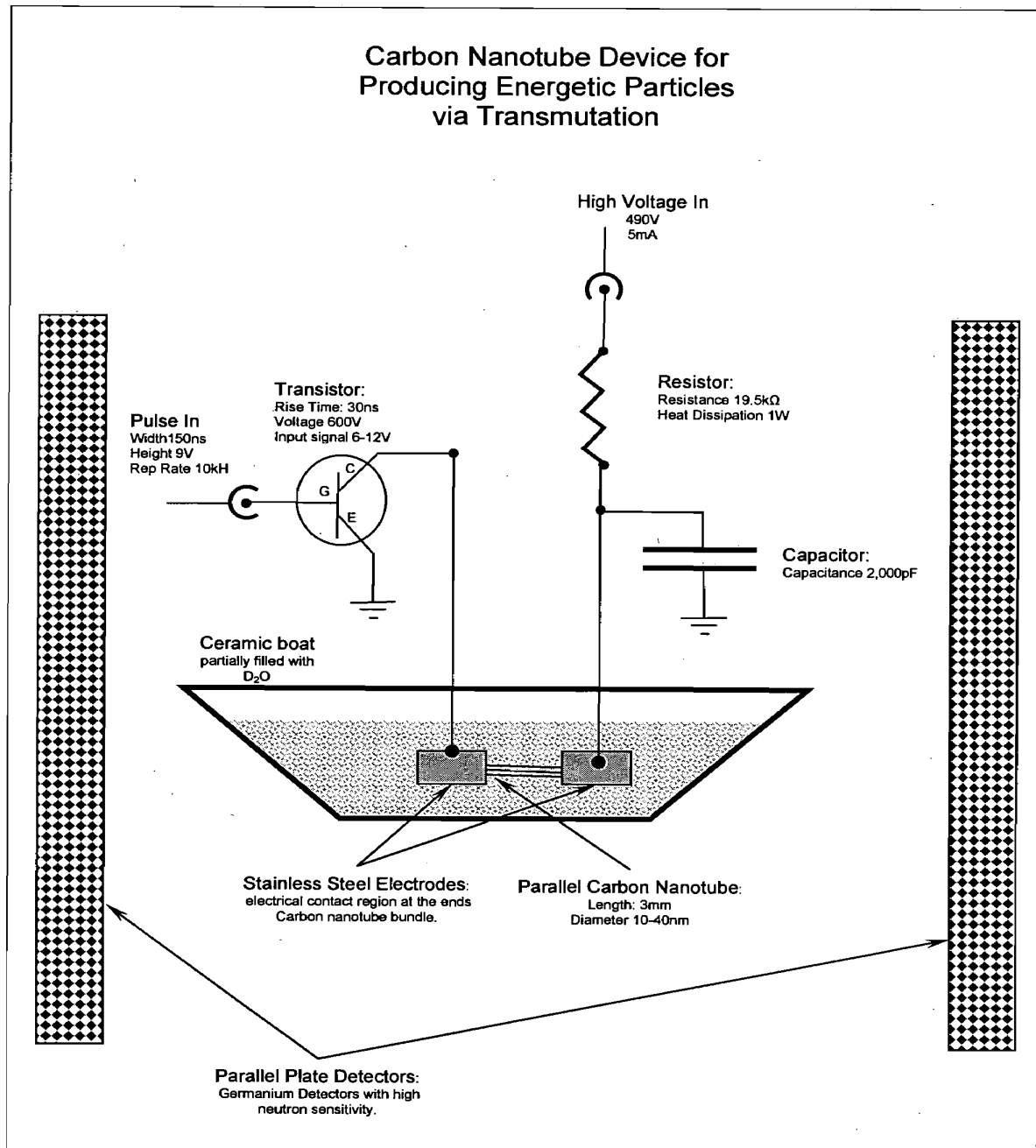


Figure 3

Carbon Nanotube Deuterium Transmutation Wet-Cell & Driving Circuit

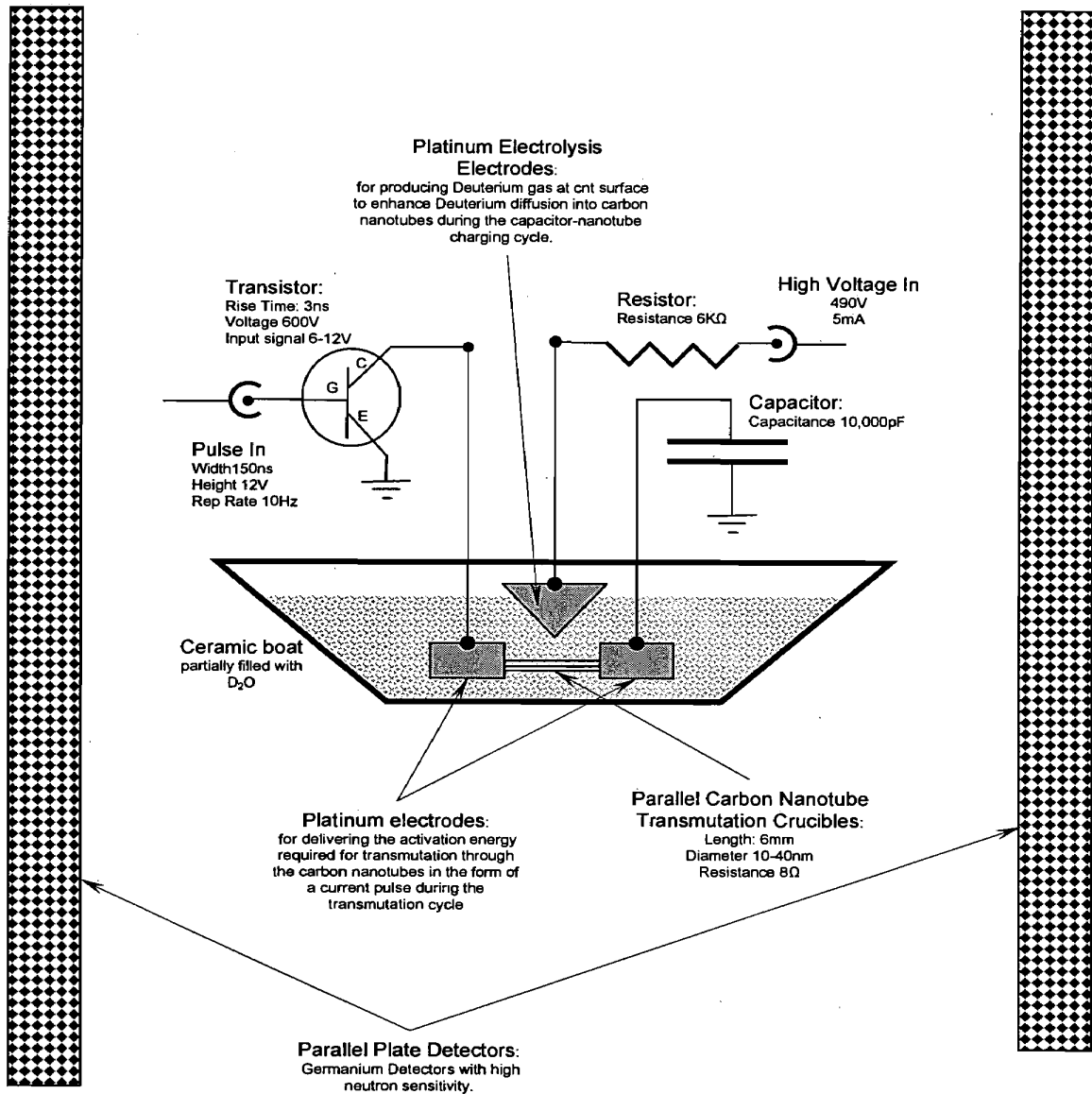


Figure 4

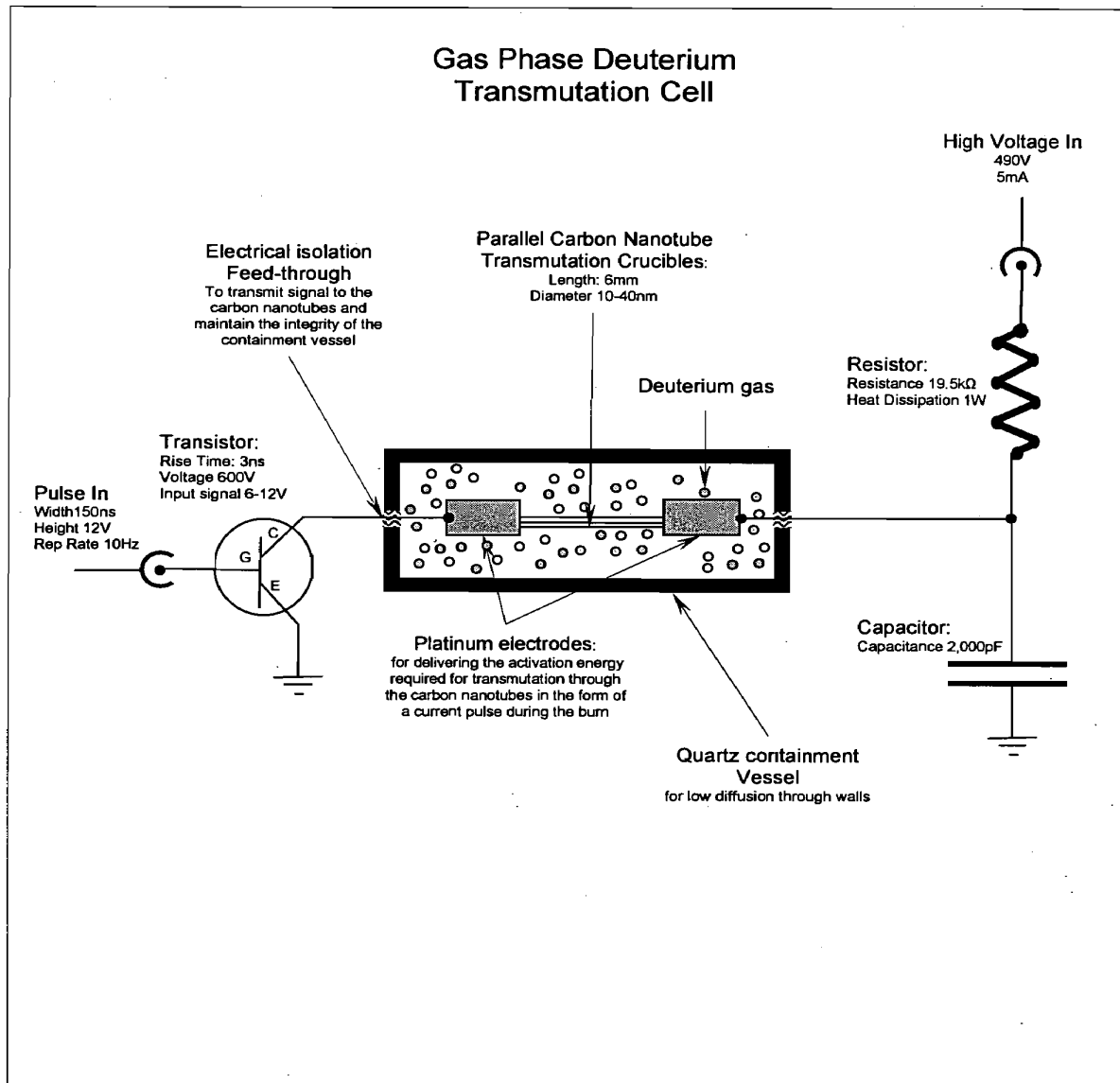
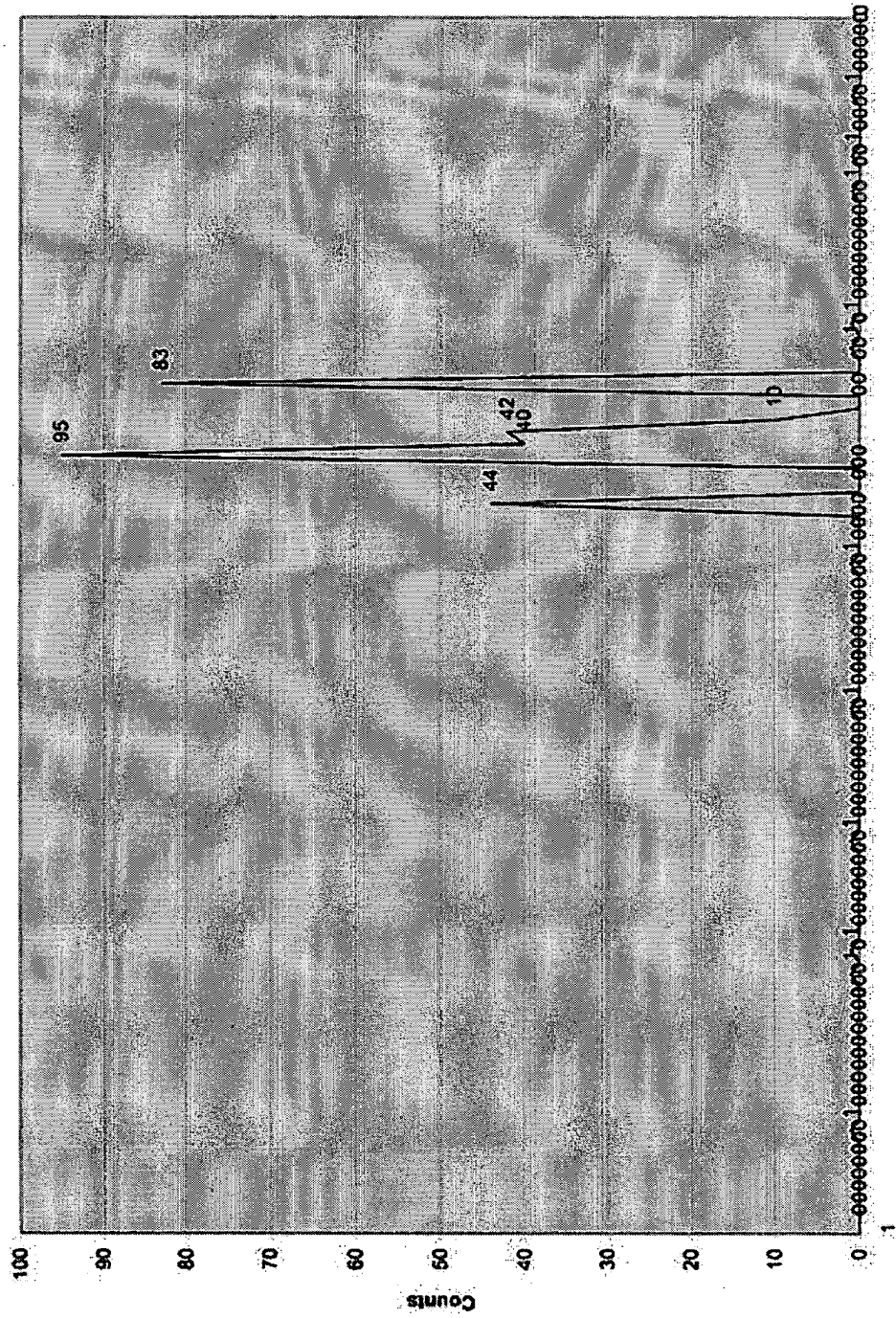


Figure 5

11/21/2006

Figure 6
Hour 2



Seconds/4 (T=22600/4 to 22700/4)
25 Oct 2006 Data Run, Higher D concentration, linear Y axis see Hour 2 chart.xls

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2006/045753

A. CLASSIFICATION OF SUBJECT MATTER

INV. G21B3/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G21B G21G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|-----------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|
| X | WO 2005/001845 A (ROSEN LOWELL [US]; GAZDZINSKI ROBERT F [US]) 6 January 2005 (2005-01-06) | 1-3,6,7, 9-11,14, 17, 19-21,24 |
| Y | page 36, line 1 - line 29 page 41, line 13 - line 27 page 47, line 19 - page 48, line 3 page 49, line 10 - line 13 | 12,13, 15,16, 18,22,23 |
| X | WO 2005/065095 A (GAIDIS JAMES MICHAEL [US]) 21 July 2005 (2005-07-21) | 1-6, 8-10,14, 20 |
| Y | page 5, line 25 - line 28 page 7, line 14 - page 8, line 26 | 12 |
| | ----- -/-- | |

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

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Date of the actual completion of the international search

26 October 2007

Date of mailing of the international search report

06/11/2007

Name and mailing address of the ISA/

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Fax: (+31-70) 340-3016

Authorized officer

Capostagno, Eros

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2006/045753

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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|-----------|-------------------------------------------------------------------------------------------------------------|------------------------|
| X | EP 1 551 032 A1 (OSAKA IND PROMOTION ORG [JP]) 6 July 2005 (2005-07-06) | 1-3, 6-10,14, 20 |
| Y | paragraph [0011] paragraph [0014] paragraph [0044] paragraph [0067] ----- | 15,16 |
| Y | US 2005/238565 A1 (SULLIVAN STEVEN [US]) 27 October 2005 (2005-10-27) paragraph [0059] ----- | 13 |
| Y | WO 99/65821 A (UNIV NEW YORK [US]) 23 December 1999 (1999-12-23) page 7, line 22 - line 25 ----- | 18 |
| Y | WO 90/13129 A (MASSACHUSETTS INST TECHNOLOGY [US]) 1 November 1990 (1990-11-01) claims 3,118 ----- | 22,23 |

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2006/045753

| Patent document cited in search report | | Publication date | Patent family member(s) | Publication date |
|-------------------------------------------|----|---------------------|------------------------------------------------------------------------|------------------------------------------------------|
| WO 2005001845 | A | 06-01-2005 | AU 2004252873 A1 CA 2529163 A1 EP 1642301 A2 | 06-01-2005 06-01-2005 05-04-2006 |
| WO 2005065095 | A | 21-07-2005 | NONE | |
| EP 1551032 | A1 | 06-07-2005 | AU 2003271180 A1 WO 2004034406 A1 US 2006153752 A1 | 04-05-2004 22-04-2004 13-07-2006 |
| US 2005238565 | A1 | 27-10-2005 | CA 2564911 A1 EP 1753902 A2 US 2007163702 A1 WO 2005103347 A2 | 03-11-2005 21-02-2007 19-07-2007 03-11-2005 |
| WO 9965821 | A | 23-12-1999 | CA 2335449 A1 EP 1089938 A1 JP 2002518280 T | 23-12-1999 11-04-2001 25-06-2002 |
| WO 9013129 | A | 01-11-1990 | NONE | |

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

| | | |
|-----------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|
| Applicant's or agent's file reference 9102.14-4304 | FOR FURTHER ACTION <div style="float: right; font-size: small;">see Form PCT/ISA/220 as well as, where applicable, item 5 below.</div> | |
| International application No. PCT/US2011/066992 | International filing date (<i>day/month/year</i>) 22/12/2011 | (Earliest) Priority Date (<i>day/month/year</i>) 24/12/2010 |
| Applicant COOPER, CHRISTOPHER H. | | |

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 4 sheets.

☒

It is also accompanied by a copy of each prior art document cited in this report.

1. Basis of the report

a. With regard to the **language**, the international search was carried out on the basis of:

☒

the international application in the language in which it was filed

☐

a translation of the international application into _____, which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b))

b. ☐ This international search report has been established taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rule 43.6**bis**(a)).

c. ☐ With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, see Box No. I.

2. ☐ **Certain claims were found unsearchable** (See Box No. II)

3. ☐ **Unity of invention is lacking** (see Box No III)

4. With regard to the **title**,

☒

the text is approved as submitted by the applicant

☐

the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,

☒

the text is approved as submitted by the applicant

☐

the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box No. IV. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority

6. With regard to the **drawings**,

a. the figure of the **drawings** to be published with the abstract is Figure No. 1

☐

as suggested by the applicant

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as selected by this Authority, because the applicant failed to suggest a figure

☐

as selected by this Authority, because this figure better characterizes the invention

b. ☐ none of the figures is to be published with the abstract

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2011/066992

A. CLASSIFICATION OF SUBJECT MATTER

INV. G21B3/00

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------|
| X | US 2008/123793 A1 (LOAN JAMES F [US] ET AL) 29 May 2008 (2008-05-29) | 1,3,4,7, 8,10,12, 16-18, 22,23, 25,26, 28,29, 36,37,39 |
| A | paragraph [0005] - paragraph [0006] paragraph [0017] paragraph [0033] paragraph [0037] paragraph [0042] - paragraph [0044] paragraph [0070] paragraph [0074] ----- -/-- | 13,32 |



Further documents are listed in the continuation of Box C.



See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

21 March 2012

Date of mailing of the international search report

05/04/2012

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NL - 2280 HV Rijswijk
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Fax: (+31-70) 340-3016

Authorized officer

Capostagno, Eros

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2011/066992

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|
| X | WO 2007/102860 A2 (SELDON TECHNOLOGIES LLC [US]; LOAN JAMES F [US]; COOPER WILLIAM K [US]) 13 September 2007 (2007-09-13) | 1,3-6,9, 18,26, 28-30, 36,37,39 |
| A | paragraph [0005] paragraph [0021] - paragraph [0024] paragraph [0027] - paragraph [0033] paragraph [0042] paragraph [0046] paragraph [0053] paragraph [0062] ----- | 13,21, 32,38 |
| A | WO 2005/065095 A2 (GAIDIS JAMES MICHAEL [US]) 21 July 2005 (2005-07-21) page 7, line 14 - page 9, line 12 ----- | 1,18,26, 36 |
| A | EP 1 551 032 A1 (OSAKA IND PROMOTION ORG [JP] ARATA YOSHIKI [JP]) 6 July 2005 (2005-07-06) paragraph [0011] paragraph [0044] ----- | 1,18,26, 36 |

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2011/066992

| Patent document cited in search report | | Publication date | Patent family member(s) | Publication date |
|-------------------------------------------|----|---------------------|----------------------------|---------------------|
| US 2008123793 | A1 | 29-05-2008 | EP 2002448 A2 | 17-12-2008 |
| | | | TW 200807445 A | 01-02-2008 |
| | | | US 2008123793 A1 | 29-05-2008 |
| | | | WO 2007117475 A2 | 18-10-2007 |
| ----- | | | | |
| WO 2007102860 | A2 | 13-09-2007 | AR 057968 A1 | 26-12-2007 |
| | | | CA 2632488 A1 | 13-09-2007 |
| | | | CL 33962006 A1 | 15-02-2008 |
| | | | CN 101356588 A | 28-01-2009 |
| | | | EP 1958208 A2 | 20-08-2008 |
| | | | JP 2009518646 A | 07-05-2009 |
| | | | KR 20080074218 A | 12-08-2008 |
| | | | PE 09222007 A1 | 27-10-2007 |
| | | | US 2009147906 A1 | 11-06-2009 |
| | | | UY 29990 A1 | 29-06-2007 |
| | | | WO 2007102860 A2 | 13-09-2007 |
| ----- | | | | |
| WO 2005065095 | A2 | 21-07-2005 | NONE | |
| ----- | | | | |
| EP 1551032 | A1 | 06-07-2005 | AU 2003271180 A1 | 04-05-2004 |
| | | | EP 1551032 A1 | 06-07-2005 |
| | | | US 2006153752 A1 | 13-07-2006 |
| | | | WO 2004034406 A1 | 22-04-2004 |
| ----- | | | | |

Electronic Acknowledgement Receipt

| | |
|---------------------------------------------|--------------------------------------------------------------------------------|
| EFS ID: | 15678736 |
| Application Number: | 13591162 |
| International Application Number: | |
| Confirmation Number: | 1832 |
| Title of Invention: | METHODS OF GENERATING ENERGETIC PARTICLES USING NANOTUBES AND ARTICLES THEREOF |
| First Named Inventor/Applicant Name: | Christopher H. Cooper |
| Customer Number: | 68540 |
| Filer: | Louis M. Troilo/Nicole Bridges |
| Filer Authorized By: | Louis M. Troilo |
| Attorney Docket Number: | 1112.0001-05000 |
| Receipt Date: | 02-MAY-2013 |
| Filing Date: | 21-AUG-2012 |
| Time Stamp: | 17:37:20 |
| Application Type: | Utility under 35 USC 111(a) |

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| 1 | Transmittal Letter | 2013-05-02_IDS_Transmittal_A sfiled.pdf | 56095 63e2e4d7151495d17bcb0bcb6af9772ec5c59c | no | 3 |

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| | | | 2046f2041858604d9689dfdc4992733ddf6bf2a | | |
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| 3 | Foreign Reference | WO2005001845A2.pdf | 5581085 | no | 115 |
| | | | 1ec38062d04bf7cdd11bc1b7d126a28e08d0c7a7 | | |
| Warnings: | | | | | |
| Information: | | | | | |
| 4 | Foreign Reference | WO2005065095A2.pdf | 1451165 | no | 31 |
| | | | ab55f8e924d35fb48e8f3cdbe3c8c140f6e90f04 | | |
| Warnings: | | | | | |
| Information: | | | | | |
| 5 | Foreign Reference | EP1551032A1.pdf | 884864 | no | 26 |
| | | | 6d1598fc20588505c28a3ebcc67b7d8ee7d30a16 | | |
| Warnings: | | | | | |
| Information: | | | | | |
| 6 | Foreign Reference | WO9965821A1.pdf | 4934293 | no | 68 |
| | | | f1e2b602878660892f007cc206af059defc0ee91 | | |
| Warnings: | | | | | |
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| 7 | Foreign Reference | WO9013129A2.pdf | 2831986 | no | 68 |
| | | | c64dd9c2e4d651badbab9f8b0f956a166ae8508b | | |
| Warnings: | | | | | |
| Information: | | | | | |
| 8 | Foreign Reference | WO2007102860A2.pdf | 1771232 | no | 26 |
| | | | 70400888d87ca08ad522c708da5672ed07a10070 | | |
| Warnings: | | | | | |
| Information: | | | | | |
| 9 | Other Reference-Patent/App/Search documents | ISRPTUS2006045753.pdf | 92258 | no | 3 |
| | | | aada389799cde4ab58207094a997594c115cc39 | | |
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| 10 | Other Reference-Patent/App/Search documents | ISRPTUS2011066992.pdf | 128359 | no | 4 |
| | | | 58daff9011ef7ba1e4fb90082bc2be7cc6108ca7 | | |

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| 11 | Non Patent Literature | Melechko.pdf | 3631278 | no | 39 |
| | | | 3363a3fa67c55cc759397885741049192d8a7930 | | |
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| 12 | Non Patent Literature | Naguib.pdf | 1190539 | no | 7 |
| | | | ab24c6f53472a905f421bf9b47d0e9bb007f73ea | | |
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| 13 | Non Patent Literature | Zidan.pdf | 394819 | no | 4 |
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| 14 | Non Patent Literature | srinivasan-04292013104840.pdf | 98922 | no | 2 |
| | | | 4b44c6eb63fb563aec47f81fc4670a09087ba3a9 | | |
| Warnings: | | | | | |
| Information: | | | | | |
| 15 | Non Patent Literature | zhang-04292013104955.pdf | 421185 | no | 5 |
| | | | a0b9c78e5be398f96efc29a955edd9fd5ed503d6 | | |
| Warnings: | | | | | |
| Information: | | | | | |
| 16 | Non Patent Literature | nist-04292013105110.pdf | 281569 | no | 5 |
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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

| | | |
|------------------------------|---|-----------------------|
| In re Application of: |) | |
| |) | |
| Christopher H. COOPER et al. |) | Group Art Unit: 1736 |
| |) | |
| Application No.: 13/591,162 |) | Examiner: TBD |
| |) | |
| Filing Date: August 21, 2012 |) | |
| |) | Confirmation No. 1832 |
| For: METHODS OF GENERATING |) | |
| ENERGETIC PARTICLES USING |) | |
| NANOTUBES AND ARTICLES |) | |
| THEREOF |) | |

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Madam:

INFORMATION DISCLOSURE STATEMENT

Pursuant to 37 C.F.R. §§ 1.56 and 1.97(b), Applicants bring to the attention of the Examiner the documents on the attached listing. This Information Disclosure Statement is being filed before the mailing date of a first Office Action in the above-referenced application.

Copies of the listed foreign and non-patent literature documents are attached.
Copies of the U.S. patent publications are not enclosed.

With respect to the non-patent literature documents, Applicants submit the following remarks:

1. **KEFU FU et al., "Deuterium attachment to carbon nanotubes in deuterated water," March 20, 2004, J. Am. Chem. Soc., Vol. 126, No. 14, pp. 4669-**

75 – As a copy of this reference was previously submitted to the United States Patent and Trademark Office on March 14, 2007 during prosecution of U.S. Patent Application No. 11/633,524, which the present application claims the benefit of, this document is not submitted herewith.

2. **DENG-ZHU GUO et al., "Visible-light induced water-splitting in channels of carbon nanotubes," Jan. 7, 2006, J. Phys. Chem. B, Vol. 110, No. 4, pp. 1571-75** – As a copy of this reference was previously submitted to the United States Patent and Trademark Office on March 14, 2007 during prosecution of U.S. Patent Application No. 11/633,524, which the present application claims the benefit of, this document is not submitted herewith.

Applicant respectfully requests that the Examiner consider the listed documents and indicate that they were considered by making appropriate notations on the attached form.

This submission does not represent that a search has been made or that no better art exists and does not constitute an admission that each or all of the listed documents are material or constitute "prior art." If the Examiner applies any of the documents as prior art against any claims in the application and Applicants determine that the cited documents do not constitute "prior art" under United States law, Applicants reserve the right to present to the U.S. Patent and Trademark Office the relevant facts and law regarding the appropriate status of such documents.

Applicants further reserve the right to take appropriate action to establish the patentability of the disclosed invention over the listed documents, should one or more of the documents be applied against the claims of the present application.

If there is any fee due in connection with the filing of this Statement, please
charge the fee to our Deposit Account No. 50-4126.

Respectfully submitted,

O'BRIEN JONES^{PLLC}

/Louis Troilo/

Dated: May 2, 2013

By: _____
Louis M. Troilo
Reg. No. 45,284



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|-----------------------|--------------------------|-----------------|---------------|-----------------|------------|------------|
| 13/591,162 | 08/21/2012 | 1736 | 722 | 1112.0001-05000 | 24 | 2 |

CONFIRMATION NO. 1832

UPDATED FILING RECEIPT



68540
O'BRIEN JONES, PLLC
1951 Kidwell Drive
Suite 740
Tysons Corner, VA 22182

Date Mailed: 01/02/2013

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Inventor(s)

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James F. Loan, Turners Falls, MA;
William K. Cooper, Santa Fe, NM;
Alan G. Cummings, Hartland, VT;

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Alan G. Cummings, Hartland, VT;

Assignment For Published Patent Application

SELDON TECHNOLOGIES, LLC, Windsor, VT

Power of Attorney: The patent practitioners associated with Customer Number 22852

Domestic Priority data as claimed by applicant

This application is a CON of 12/898,807 10/06/2010 ABN
which is a CON of 12/258,568 10/27/2008 ABN
which is a CON of 11/633,524 12/05/2006 ABN
which claims benefit of 60/741,874 12/05/2005
and claims benefit of 60/777,577 03/01/2006

Foreign Applications for which priority is claimed (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see <http://www.uspto.gov> for more information.) - None.

Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.

If Required, Foreign Filing License Granted: 09/05/2012

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 13/591,162**

Projected Publication Date: 04/11/2013

Non-Publication Request: No

Early Publication Request: No

**** SMALL ENTITY ****

Title

METHODS OF GENERATING ENERGETIC PARTICLES USING NANOTUBES AND ARTICLES THEREOF

Preliminary Class

423

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at <http://www.uspto.gov/web/offices/pac/doc/general/index.html>.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, <http://www.stopfakes.gov>. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4158).

LICENSE FOR FOREIGN FILING UNDER
Title 35, United States Code, Section 184
Title 37, Code of Federal Regulations, 5.11 & 5.15

GRANTED

The applicant has been granted a license under 35 U.S.C. 184, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" followed by a date appears on this form. Such licenses are issued in all applications where the conditions for issuance of a license have been met, regardless of whether or not a license may be required as set forth in 37 CFR 5.15. The scope and limitations of this license are set forth in 37 CFR 5.15(a) unless an earlier license has been issued under 37 CFR 5.15(b). The license is subject to revocation upon written notification. The date indicated is the effective date of the license, unless an earlier license of similar scope has been granted under 37 CFR 5.13 or 5.14.

This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign Assets Control, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

SelectUSA

The United States represents the largest, most dynamic marketplace in the world and is an unparalleled location for business investment, innovation and commercialization of new technologies. The USA offers tremendous resources and advantages for those who invest and manufacture goods here. Through SelectUSA, our nation works to encourage, facilitate, and accelerate business investment. To learn more about why the USA is the best country in the world to develop technology, manufacture products, and grow your business, visit SelectUSA.gov.

PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number
13/591,162

APPLICATION AS FILED - PART I

(Column 1)

(Column 2)

SMALL ENTITY

OR

OTHER THAN SMALL ENTITY

| FOR | NUMBER FILED | NUMBER EXTRA |
|---------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|
| BASIC FEE (37 CFR 1.16(a), (b), or (c)) | N/A | N/A |
| SEARCH FEE (37 CFR 1.16(k), (i), or (m)) | N/A | N/A |
| EXAMINATION FEE (37 CFR 1.16(o), (p), or (q)) | N/A | N/A |
| TOTAL CLAIMS (37 CFR 1.16(i)) | 24 minus 20 = | * 4 |
| INDEPENDENT CLAIMS (37 CFR 1.16(h)) | 2 minus 3 = | * |
| APPLICATION SIZE FEE (37 CFR 1.16(s)) | If the specification and drawings exceed 100 sheets of paper, the application size fee due is \$310 (\$155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s). | |
| MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j)) | | |

| RATE(\$) | FEE(\$) |
|----------|---------|
| N/A | 98 |
| N/A | 310 |
| N/A | 125 |
| x 31 = | 124 |
| x 125 = | 0.00 |
| | 0.00 |
| | 0.00 |
| TOTAL | 657 |

| RATE(\$) | FEE(\$) |
|----------|---------|
| N/A | |
| N/A | |
| N/A | |
| | |
| | |
| | |
| TOTAL | |

* If the difference in column 1 is less than zero, enter "0" in column 2.

APPLICATION AS AMENDED - PART II

(Column 1)

(Column 2)

(Column 3)

SMALL ENTITY

OR

OTHER THAN SMALL ENTITY

| AMENDMENT A | | CLAIMS REMAINING AFTER AMENDMENT | | HIGHEST NUMBER PREVIOUSLY PAID FOR | PRESENT EXTRA |
|-------------|-----------------------------------------------------------------|-------------------------------------------|-------|---------------------------------------------|------------------|
| | Total (37 CFR 1.16(i)) | * | Minus | ** | = |
| | Independent (37 CFR 1.16(h)) | * | Minus | *** | = |
| | Application Size Fee (37 CFR 1.16(s)) | | | | |
| | FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j)) | | | | |

| RATE(\$) | ADDITIONAL FEE(\$) |
|--------------------|--------------------|
| x = | |
| x = | |
| | |
| | |
| TOTAL ADD'L FEE | |

| RATE(\$) | ADDITIONAL FEE(\$) |
|--------------------|--------------------|
| x = | |
| x = | |
| | |
| | |
| TOTAL ADD'L FEE | |

(Column 1)

(Column 2)

(Column 3)

| AMENDMENT B | | CLAIMS REMAINING AFTER AMENDMENT | | HIGHEST NUMBER PREVIOUSLY PAID FOR | PRESENT EXTRA |
|-----------------------------------------------------------------|---------------------------------------|-------------------------------------------|-------|---------------------------------------------|------------------|
| | Total (37 CFR 1.16(i)) | * | Minus | ** | = |
| | Independent (37 CFR 1.16(h)) | * | Minus | *** | = |
| | Application Size Fee (37 CFR 1.16(s)) | | | | |
| FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j)) | | | | | |

| RATE(\$) | ADDITIONAL FEE(\$) |
|--------------------|--------------------|
| x = | |
| x = | |
| | |
| | |
| TOTAL ADD'L FEE | |

| RATE(\$) | ADDITIONAL FEE(\$) |
|--------------------|--------------------|
| x = | |
| x = | |
| | |
| | |
| TOTAL ADD'L FEE | |

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.

** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".

*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".

The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.

PATENT
Customer No. 68,540
Attorney Docket No. 1112.0001-05000

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

| | | |
|------------------------------|---|------------------------|
| In re Application of: |) | |
| |) | |
| Christopher H. COOPER et al. |) | Group Art Unit: 1736 |
| |) | |
| Application No.: 13/591,162 |) | Examiner: TBA |
| |) | |
| Filed: August 21, 2012 |) | |
| |) | Confirmation No.: 1832 |
| For: METHODS OF GENERATING |) | |
| ENERGETIC PARTICLES USING |) | |
| NANOTUBES AND ARTICLES |) | |
| THEREOF |) | |

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

RESPONSE TO NOTICE TO FILE MISSING PARTS

In response to the Notice to File Missing Parts under 35 U.S.C. 371 dated September 10, 2012, Applicants submit, the basic filing fee of \$98.00, the search fee of \$310.00, the examination fee of \$125.00, the additional claims fee of \$124.00 and the required surcharge of \$65.00. The aforementioned fees are being provided via deposit account authorization using the U.S. Patent and Trademark Office Electronic Filing System (EFS).

Please grant any extensions of time required to enter this response, and charge any required fees not otherwise accounted for to our Deposit Account No. 50-4126.

12/18/2012 VVAN11 00000014 504126 13591162
01 FC:2251 75.00 DA

Respectfully submitted,

O'BRIEN JONES^{PLLC}

Dated: December 10, 2012

By: /Louis M. Troilo, Reg. No. 45,284/
Louis M. Troilo
Reg. No. 45,284

Electronic Acknowledgement Receipt

| | |
|---------------------------------------------|--------------------------------------------------------------------------------|
| EFS ID: | 14428683 |
| Application Number: | 13591162 |
| International Application Number: | |
| Confirmation Number: | 1832 |
| Title of Invention: | METHODS OF GENERATING ENERGETIC PARTICLES USING NANOTUBES AND ARTICLES THEREOF |
| First Named Inventor/Applicant Name: | Christopher H. Cooper |
| Customer Number: | 68540 |
| Filer: | Louis M. Troilo/Wallace Clegg |
| Filer Authorized By: | Louis M. Troilo |
| Attorney Docket Number: | 1112.0001-05000 |
| Receipt Date: | 10-DEC-2012 |
| Filing Date: | 21-AUG-2012 |
| Time Stamp: | 17:58:24 |
| Application Type: | Utility under 35 USC 111(a) |

Payment information:

| | |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| Submitted with Payment | yes |
| Payment Type | Credit Card |
| Payment was successfully received in RAM | \$722 |
| RAM confirmation Number | 5883 |
| Deposit Account | 504126 |
| Authorized User | O'BRIEN JONES, PLLC |
| The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows: Charge any Additional Fees required under 37 C.F.R. Section 1.21 (Miscellaneous fees and charges) | |

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

| | | |
|------------------------------|---|------------------------|
| In re Application of: |) | |
| |) | |
| Christopher H. COOPER et al. |) | Group Art Unit: 1736 |
| |) | |
| Application No.: 13/591,162 |) | Examiner: TBA |
| |) | |
| Filed: August 21, 2012 |) | |
| |) | Confirmation No.: 1832 |
| For: METHODS OF GENERATING |) | |
| ENERGETIC PARTICLES USING |) | |
| NANOTUBES AND ARTICLES |) | |
| THEREOF |) | |

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

RESPONSE TO NOTICE TO FILE MISSING PARTS

In response to the Notice to File Missing Parts under 35 U.S.C. 371 dated September 10, 2012, Applicants submit, the basic filing fee of \$98.00, the search fee of \$310.00, the examination fee of \$125.00, the additional claims fee of \$124.00 and the required surcharge of \$65.00. The aforementioned fees are being provided via deposit account authorization using the U.S. Patent and Trademark Office Electronic Filing System (EFS).

Please grant any extensions of time required to enter this response, and charge any required fees not otherwise accounted for to our Deposit Account No. 50-4126.

Respectfully submitted,

O'BRIEN JONES^{PLLC}

Dated: December 10, 2012

By: Louis M. Troilo, Reg. No. 45,284/
Louis M. Troilo
Reg. No. 45,284



UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

| APPLICATION NUMBER | FILING OR 371(C) DATE | FIRST NAMED APPLICANT | ATTY. DOCKET NO./TITLE |
|--------------------|-----------------------|-----------------------|------------------------|
| 13/591,162 | 08/21/2012 | Christopher H. Cooper | 1112.0001-04000 |

CONFIRMATION NO. 1832

FORMALITIES LETTER



OC000000056372073

68540
O'BRIEN JONES, PLLC
1951 Kidwell Drive
Suite 740
Tysons Corner, VA 22182

Date Mailed: 09/10/2012

NOTICE TO FILE MISSING PARTS OF NONPROVISIONAL APPLICATION

FILED UNDER 37 CFR 1.53(b)

Filing Date Granted

Items Required To Avoid Abandonment:

An application number and filing date have been accorded to this application. The item(s) indicated below, however, are missing. Applicant is given **TWO MONTHS** from the date of this Notice within which to file all required items below to avoid abandonment. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

- The statutory basic filing fee is missing.
Applicant must submit \$95 to complete the basic filing fee for a small entity.

The applicant needs to satisfy supplemental fees problems indicated below.

The required item(s) identified below must be timely submitted to avoid abandonment:

- Additional claim fees of \$120 as a small entity, including any required multiple dependent claim fee, are required. Applicant must submit the additional claim fees or cancel the additional claims for which fees are due.
- A surcharge (for late submission of filing fee, search fee, examination fee or oath or declaration) as set forth in 37 CFR 1.16(f) of \$65 for a small entity in compliance with 37 CFR 1.27, must be submitted.

SUMMARY OF FEES DUE:

Total fee(s) required within **TWO MONTHS** from the date of this Notice is \$715 for a small entity

- \$95 Statutory basic filing fee.
- \$65 Surcharge.
- The application search fee has not been paid. Applicant must submit \$310 to complete the search fee.
- The application examination fee has not been paid. Applicant must submit \$125 to complete the examination fee for a small entity in compliance with 37 CFR 1.27.
- Total additional claim fee(s) for this application is \$120
 - \$120 for 4 total claims over 20.

Replies should be mailed to:

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria VA 22313-1450

Registered users of EFS-Web may alternatively submit their reply to this notice via EFS-Web.
<https://portal.uspto.gov/authenticate/AuthenticateUserLocalEPF.html>

For more information about EFS-Web please call the USPTO Electronic Business Center at **1-866-217-9197** or visit our website at <http://www.uspto.gov/ebc>.

If you are not using EFS-Web to submit your reply, you must include a copy of this notice.

/bcao/

Office of Data Management, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

Electronic Patent Application Fee Transmittal

| | | | | |
|------------------------------------------------|--------------------------------------------------------------------------------|-----------------|---------------|-----------------------------|
| Application Number: | 13591162 | | | |
| Filing Date: | 21-Aug-2012 | | | |
| Title of Invention: | METHODS OF GENERATING ENERGETIC PARTICLES USING NANOTUBES AND ARTICLES THEREOF | | | |
| First Named Inventor/Applicant Name: | Christopher H. Cooper | | | |
| Filer: | Louis M. Troilo/Wallace Clegg | | | |
| Attorney Docket Number: | 1112.0001-05000 | | | |
| Filed as Small Entity | | | | |
| Utility under 35 USC 111(a) Filing Fees | | | | |
| Description | Fee Code | Quantity | Amount | Sub-Total in USD(\$) |
| Basic Filing: | | | | |
| Utility filing Fee (Electronic filing) | 4011 | 1 | 98 | 98 |
| Utility Search Fee | 2111 | 1 | 310 | 310 |
| Utility Examination Fee | 2311 | 1 | 125 | 125 |
| Pages: | | | | |
| Claims: | | | | |
| Claims in excess of 20 | 2202 | 4 | 31 | 124 |
| Miscellaneous-Filing: | | | | |
| Late filing fee for oath or declaration | 2051 | 1 | 65 | 65 |

| Description | Fee Code | Quantity | Amount | Sub-Total in USD(\$) |
|-----------------------------------|----------|----------|--------|----------------------|
| Petition: | | | | |
| Patent-Appeals-and-Interference: | | | | |
| Post-Allowance-and-Post-Issuance: | | | | |
| Extension-of-Time: | | | | |
| Miscellaneous: | | | | |
| Total in USD (\$) | | | | 722 |

Electronic Acknowledgement Receipt

| | |
|---------------------------------------------|--------------------------------------------------------------------------------|
| EFS ID: | 14428683 |
| Application Number: | 13591162 |
| International Application Number: | |
| Confirmation Number: | 1832 |
| Title of Invention: | METHODS OF GENERATING ENERGETIC PARTICLES USING NANOTUBES AND ARTICLES THEREOF |
| First Named Inventor/Applicant Name: | Christopher H. Cooper |
| Customer Number: | 68540 |
| Filer: | Louis M. Troilo/Wallace Clegg |
| Filer Authorized By: | Louis M. Troilo |
| Attorney Docket Number: | 1112.0001-05000 |
| Receipt Date: | 10-DEC-2012 |
| Filing Date: | 21-AUG-2012 |
| Time Stamp: | 17:58:24 |
| Application Type: | Utility under 35 USC 111(a) |

Payment information:

| | |
|------------------------------------------|---------------------|
| Submitted with Payment | yes |
| Payment Type | Credit Card |
| Payment was successfully received in RAM | \$722 |
| RAM confirmation Number | 5883 |
| Deposit Account | 504126 |
| Authorized User | O'BRIEN JONES, PLLC |

The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:

Charge any Additional Fees required under 37 C.F.R. Section 1.21 (Miscellaneous fees and charges)

File Listing:

| Document Number | Document Description | File Name | File Size(Bytes)/ Message Digest | Multi Part /.zip | Pages (if appl.) |
|-----------------|---------------------------------------------------|--------------------------------------------------------|----------------------------------------------------|------------------|------------------|
| 1 | Applicant Response to Pre-Exam Formalities Notice | 2012-12-10_1112-0001-05_Response_to_NTFMP_as-filed.pdf | 121208 2f53bd06af058899e99318f7d34cb497247fa1aa | no | 3 |

Warnings:**Information:**

| | | | | | |
|---|----------------------|--------------|---------------------------------------------------|----|---|
| 2 | Fee Worksheet (SB06) | fee-info.pdf | 38406 048b25a8ec882ffb4575bbf28dda307bea354eff | no | 2 |
|---|----------------------|--------------|---------------------------------------------------|----|---|

Warnings:**Information:**

| | | | |
|------------------------------|--|--|--------|
| Total Files Size (in bytes): | | | 159614 |
|------------------------------|--|--|--------|

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number
13/591,162

APPLICATION AS FILED - PART I

(Column 1)

(Column 2)

SMALL ENTITY

OR

OTHER THAN SMALL ENTITY

| FOR | NUMBER FILED | NUMBER EXTRA |
|---------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|
| BASIC FEE (37 CFR 1.16(a), (b), or (c)) | N/A | N/A |
| SEARCH FEE (37 CFR 1.16(k), (i), or (m)) | N/A | N/A |
| EXAMINATION FEE (37 CFR 1.16(o), (p), or (q)) | N/A | N/A |
| TOTAL CLAIMS (37 CFR 1.16(i)) | 24 minus 20 = | * 4 |
| INDEPENDENT CLAIMS (37 CFR 1.16(h)) | 2 minus 3 = | * |
| APPLICATION SIZE FEE (37 CFR 1.16(s)) | If the specification and drawings exceed 100 sheets of paper, the application size fee due is \$310 (\$155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s). | |
| MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j)) | | |

| RATE(\$) | FEE(\$) |
|----------|---------|
| N/A | 95 |
| N/A | 310 |
| N/A | 125 |
| x 30 = | 120 |
| x 125 = | 0.00 |
| | 0.00 |
| | 0.00 |
| TOTAL | 650 |

| RATE(\$) | FEE(\$) |
|----------|---------|
| N/A | |
| N/A | |
| N/A | |
| | |
| | |
| | |
| TOTAL | |

* If the difference in column 1 is less than zero, enter "0" in column 2.

APPLICATION AS AMENDED - PART II

(Column 1)

(Column 2)

(Column 3)

SMALL ENTITY

OR

OTHER THAN SMALL ENTITY

| AMENDMENT A | | CLAIMS REMAINING AFTER AMENDMENT | | HIGHEST NUMBER PREVIOUSLY PAID FOR | PRESENT EXTRA |
|-------------|-----------------------------------------------------------------|----------------------------------|-------|------------------------------------|---------------|
| | Total (37 CFR 1.16(i)) | * | Minus | ** | = |
| | Independent (37 CFR 1.16(h)) | * | Minus | *** | = |
| | Application Size Fee (37 CFR 1.16(s)) | | | | |
| | FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j)) | | | | |

| RATE(\$) | ADDITIONAL FEE(\$) |
|--------------------|--------------------|
| x = | |
| x = | |
| | |
| | |
| TOTAL ADD'L FEE | |

| RATE(\$) | ADDITIONAL FEE(\$) |
|--------------------|--------------------|
| x = | |
| x = | |
| | |
| | |
| TOTAL ADD'L FEE | |

(Column 1)

(Column 2)

(Column 3)

| AMENDMENT B | | CLAIMS REMAINING AFTER AMENDMENT | | HIGHEST NUMBER PREVIOUSLY PAID FOR | PRESENT EXTRA |
|-------------|-----------------------------------------------------------------|----------------------------------|-------|------------------------------------|---------------|
| | Total (37 CFR 1.16(i)) | * | Minus | ** | = |
| | Independent (37 CFR 1.16(h)) | * | Minus | *** | = |
| | Application Size Fee (37 CFR 1.16(s)) | | | | |
| | FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j)) | | | | |

| RATE(\$) | ADDITIONAL FEE(\$) |
|--------------------|--------------------|
| x = | |
| x = | |
| | |
| | |
| TOTAL ADD'L FEE | |

| RATE(\$) | ADDITIONAL FEE(\$) |
|--------------------|--------------------|
| x = | |
| x = | |
| | |
| | |
| TOTAL ADD'L FEE | |

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.

** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".

*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".

The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.



UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

| APPLICATION NUMBER | FILING or 371(c) DATE | GRP ART UNIT | FIL FEE REC'D | ATTY. DOCKET NO | TOT CLAIMS | IND CLAIMS |
|-----------------------|--------------------------|-----------------|---------------|-----------------|------------|------------|
| 13/591,162 | 08/21/2012 | 1736 | 0.00 | 1112.0001-04000 | 24 | 2 |

CONFIRMATION NO. 1832

68540
O'BRIEN JONES, PLLC
1951 Kidwell Drive
Suite 740
Tysons Corner, VA 22182

FILING RECEIPT



OC000000056372072

Date Mailed: 09/10/2012

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Applicant(s)

Christopher H. Cooper, Windsor, VT;
James F. Loan, Turners Falls, MA;
William K. Cooper, Santa Fe, NM;
Alan G. Cummings, Hartland, VT;

Assignment For Published Patent Application

SELDON TECHNOLOGIES, LLC, Windsor, VT

Power of Attorney: The patent practitioners associated with Customer Number 22852

Domestic Priority data as claimed by applicant

This application is a CON of 12/898,807 10/06/2010
which is a CON of 12/258,568 10/27/2008 ABN
which is a CON of 11/633,524 12/05/2006 ABN
which claims benefit of 60/741,874 12/05/2005
and claims benefit of 60/777,577 03/01/2006

Foreign Applications (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see <http://www.uspto.gov> for more information.)

If Required, Foreign Filing License Granted: 09/05/2012

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 13/591,162**

Projected Publication Date: To Be Determined - pending completion of Missing Parts

Non-Publication Request: No

Early Publication Request: No

**** SMALL ENTITY ****

Title

METHODS OF GENERATING ENERGETIC PARTICLES USING NANOTUBES AND ARTICLES THEREOF

Preliminary Class

423

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at <http://www.uspto.gov/web/offices/pac/doc/general/index.html>.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, <http://www.stopfakes.gov>. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4158).

LICENSE FOR FOREIGN FILING UNDER
Title 35, United States Code, Section 184
Title 37, Code of Federal Regulations, 5.11 & 5.15

GRANTED

The applicant has been granted a license under 35 U.S.C. 184, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" followed by a date appears on this form. Such licenses are issued in all applications where the conditions for issuance of a license have been met, regardless of whether or not a license may be required as set forth in 37 CFR 5.15. The scope and limitations of this license are set forth in 37 CFR 5.15(a) unless an earlier license has been issued under 37 CFR 5.15(b). The license is subject to revocation upon written notification. The date indicated is the effective date of the license, unless an earlier license of similar scope has been granted under 37 CFR 5.13 or 5.14.

This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign Assets Control, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

SelectUSA

The United States represents the largest, most dynamic marketplace in the world and is an unparalleled location for business investment, innovation and commercialization of new technologies. The USA offers tremendous resources and advantages for those who invest and manufacture goods here. Through SelectUSA, our nation works to encourage, facilitate, and accelerate business investment. To learn more about why the USA is the best country in the world to develop technology, manufacture products, and grow your business, visit SelectUSA.gov.



UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

| APPLICATION NUMBER | FILING OR 371(C) DATE | FIRST NAMED APPLICANT | ATTY. DOCKET NO./TITLE |
|--------------------|-----------------------|-----------------------|------------------------|
| 13/591,162 | 08/21/2012 | Christopher H. Cooper | 1112.0001-04000 |

CONFIRMATION NO. 1832

FORMALITIES LETTER



OC000000056372073

68540
O'BRIEN JONES, PLLC
1951 Kidwell Drive
Suite 740
Tysons Corner, VA 22182

Date Mailed: 09/10/2012

NOTICE TO FILE MISSING PARTS OF NONPROVISIONAL APPLICATION

FILED UNDER 37 CFR 1.53(b)

Filing Date Granted

Items Required To Avoid Abandonment:

An application number and filing date have been accorded to this application. The item(s) indicated below, however, are missing. Applicant is given **TWO MONTHS** from the date of this Notice within which to file all required items below to avoid abandonment. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

- The statutory basic filing fee is missing.
Applicant must submit \$95 to complete the basic filing fee for a small entity.

The applicant needs to satisfy supplemental fees problems indicated below.

The required item(s) identified below must be timely submitted to avoid abandonment:

- Additional claim fees of \$120 as a small entity, including any required multiple dependent claim fee, are required. Applicant must submit the additional claim fees or cancel the additional claims for which fees are due.
- A surcharge (for late submission of filing fee, search fee, examination fee or oath or declaration) as set forth in 37 CFR 1.16(f) of \$65 for a small entity in compliance with 37 CFR 1.27, must be submitted.

SUMMARY OF FEES DUE:

Total fee(s) required within **TWO MONTHS** from the date of this Notice is \$715 for a small entity

- \$95 Statutory basic filing fee.
- \$65 Surcharge.
- The application search fee has not been paid. Applicant must submit \$310 to complete the search fee.
- The application examination fee has not been paid. Applicant must submit \$125 to complete the examination fee for a small entity in compliance with 37 CFR 1.27.
- Total additional claim fee(s) for this application is \$120
 - \$120 for 4 total claims over 20.

Replies should be mailed to:

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria VA 22313-1450

Registered users of EFS-Web may alternatively submit their reply to this notice via EFS-Web.
<https://portal.uspto.gov/authenticate/AuthenticateUserLocalEPF.html>

For more information about EFS-Web please call the USPTO Electronic Business Center at **1-866-217-9197** or visit our website at <http://www.uspto.gov/ebc>.

If you are not using EFS-Web to submit your reply, you must include a copy of this notice.

/bcao/

Office of Data Management, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

PATENT
Customer No. 68,540
Attorney Docket No. 1112.0001-04000

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

| | | |
|-----------------------------------|---|------------------------------------|
| In re Application of: |) | |
| |) | |
| Christopher H. COOPER et al. |) | Group Art Unit: Not Yet Assigned |
| |) | |
| Application No.: Not Yet Assigned |) | Examiner: Not Yet Assigned |
| |) | |
| Filed: Concurrently Herewith |) | |
| |) | |
| For: METHODS OF GENERATING |) | Confirmation No.: Not Yet Assigned |
| ENERGETIC PARTICLES USING |) | |
| NANOTUBES AND ARTICLES |) | |
| THEREOF |) | |

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

PRELIMINARY AMENDMENT

Prior to the examination of the above application, please amend this application
as follows:

Amendments to the Specification are included in this paper.

Remarks/Arguments follow the amendment sections of this paper.

AMENDMENTS TO THE SPECIFICATION:

Please amend the specification as follows:

Page 1, line 1, insert the following new paragraph:

This is a continuation of Application No. 12/898,807, filed October 6, 2010, which is a continuation of U.S. Application No. 12/258,568 filed October 27, 2008, which is a continuation of U.S. Application No. 11/633,524, filed December 5, 2006, and claims the benefit of U.S. Provisional Application No. 60/741,874, filed December 5, 2005, and 60/777,577, filed March 1, 2006, all of which are incorporated by reference herein.

REMARKS

The application has been amended to insert the required reference to the parent application, for which benefit is claimed, of this new continuing application.

If there is any fee due in connection with the filing of this Preliminary Amendment, **except the filing fee**, please charge the fee to our Deposit Account No. 50-4126. If there is an extension of time due in the parent application, Application No. 12/898,807, to maintain co-pendency with this continuation application, please charge the fee to our Deposit Account No. 50-4126.

Respectfully submitted,

O'BRIEN JONES^{PLLC}

/Louis Troilo/

Dated: August 21, 2012

By: _____
Louis M. Troilo
Reg. No. 45,284

Electronic Acknowledgement Receipt

| | |
|---------------------------------------------|--------------------------------------------------------------------------------|
| EFS ID: | 13551281 |
| Application Number: | 13591162 |
| International Application Number: | |
| Confirmation Number: | 1832 |
| Title of Invention: | METHODS OF GENERATING ENERGETIC PARTICLES USING NANOTUBES AND ARTICLES THEREOF |
| First Named Inventor/Applicant Name: | Christopher H. COOPER |
| Customer Number: | 22852 |
| Filer: | Louis M. Troilo/Wallace Clegg |
| Filer Authorized By: | Louis M. Troilo |
| Attorney Docket Number: | 1112.0001-04000 |
| Receipt Date: | 21-AUG-2012 |
| Filing Date: | |
| Time Stamp: | 21:05:35 |
| Application Type: | Utility under 35 USC 111(a) |

Payment information:

| | |
|------------------------|----|
| Submitted with Payment | no |
|------------------------|----|

File Listing:

| Document Number | Document Description | File Name | File Size(Bytes)/ Message Digest | Multi Part /.zip | Pages (if appl.) |
|-----------------|------------------------|-----------------------------|-------------------------------------------------------|------------------|------------------|
| 1 | Application Data Sheet | 2012-08-21_ADS_as-filed.pdf | 41400 1eb7ce94ab0605480eb4c957322063a706a debc4 | no | 5 |

Warnings:

Information:

| | | | | | |
|-------------------------------------------------|------------------------------------------------------------|--------------------------------------------------|-----------------------------------------------------|------------|----|
| This is not an USPTO supplied ADS fillable form | | | | | |
| 2 | | 2012-08-21_Application_as-filed.pdf | 1074992 7ed0ac4e556c3a37621c8240994cff9b3d04932c | yes | 26 |
| | Multipart Description/PDF files in .zip description | | | | |
| | Document Description | | Start | End | |
| | Specification | | 1 | 17 | |
| | Claims | | 18 | 19 | |
| | Abstract | | 20 | 20 | |
| | Drawings-only black and white line drawings | | 21 | 26 | |
| Warnings: | | | | | |
| Information: | | | | | |
| 3 | Oath or Declaration filed | 2012-08-21_Declaration_and_Power_of_Attorney.pdf | 106715 11a36261c56fea181d4ff348cd7953cf1664f546 | no | 2 |
| Warnings: | | | | | |
| Information: | | | | | |
| 4 | | 2012-08-21_PreliminaryAmendment_as-filed.pdf | 71203 7b3627127d8c26e4fea0367326dbb84533d1de6b | yes | 3 |
| | Multipart Description/PDF files in .zip description | | | | |
| | Document Description | | Start | End | |
| | Preliminary Amendment | | 1 | 1 | |
| | Specification | | 2 | 2 | |
| | Applicant Arguments/Remarks Made in an Amendment | | 3 | 3 | |
| Warnings: | | | | | |
| Information: | | | | | |
| Total Files Size (in bytes): | | | 1294310 | | |

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

| | | | |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|------------------------|-----------------|
| Application Data Sheet 37 CFR 1.76 | | Attorney Docket Number | 1112.0001-04000 |
| | | Application Number | |
| Title of Invention | METHODS OF GENERATING ENERGETIC PARTICLES USING NANOTUBES AND ARTICLES THEREOF | | |
| <p>The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.</p> <p>This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.</p> | | | |

Secrecy Order 37 CFR 5.2

- ☐ Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)

Applicant Information:

| | | | | | |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|-------------------------------------------|--------------------|----------------------------------------------------------------|----|
| Applicant 1 | | | | | |
| Applicant Authority | | <input checked="" type="radio"/> Inventor | | <input type="radio"/> Legal Representative under 35 U.S.C. 117 | |
| | | | | <input type="radio"/> Party of Interest under 35 U.S.C. 118 | |
| Prefix | Given Name | Middle Name | Family Name | Suffix | |
| | Christopher | H. | Cooper | | |
| Residence Information (Select One) <input checked="" type="radio"/> US Residency <input type="radio"/> Non US Residency <input type="radio"/> Active US Military Service | | | | | |
| City | Windsor | State/Province | VT | Country of Residence | US |
| Citizenship under 37 CFR 1.41(b) | | US | | | |
| Mailing Address of Applicant: | | | | | |
| Address 1 | | 16 Pine Street | | | |
| Address 2 | | | | | |
| City | Windsor | State/Province | VT | | |
| Postal Code | 05089 | Country | US | | |
| Applicant 2 | | | | | |
| Applicant Authority | | <input checked="" type="radio"/> Inventor | | <input type="radio"/> Legal Representative under 35 U.S.C. 117 | |
| | | | | <input type="radio"/> Party of Interest under 35 U.S.C. 118 | |
| Prefix | Given Name | Middle Name | Family Name | Suffix | |
| | James | F. | Loan | | |
| Residence Information (Select One) <input checked="" type="radio"/> US Residency <input type="radio"/> Non US Residency <input type="radio"/> Active US Military Service | | | | | |
| City | Turners Falls | State/Province | MA | Country of Residence | US |
| Citizenship under 37 CFR 1.41(b) | | US | | | |
| Mailing Address of Applicant: | | | | | |
| Address 1 | | 12 Country Club Lane | | | |
| Address 2 | | | | | |
| City | Turners Falls | State/Province | MA | | |
| Postal Code | 01376 | Country | US | | |
| Applicant 3 | | | | | |
| Applicant Authority | | <input checked="" type="radio"/> Inventor | | <input type="radio"/> Legal Representative under 35 U.S.C. 117 | |
| | | | | <input type="radio"/> Party of Interest under 35 U.S.C. 118 | |
| Prefix | Given Name | Middle Name | Family Name | Suffix | |
| | William | K. | Cooper | | |
| Residence Information (Select One) <input checked="" type="radio"/> US Residency <input type="radio"/> Non US Residency <input type="radio"/> Active US Military Service | | | | | |
| City | Santa Fe | State/Province | NM | Country of Residence | US |

| | | | | | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|--------------------------------------------------------------------------------|----------------|-----------------|--|
| Application Data Sheet 37 CFR 1.76 | | Attorney Docket Number | | 1112.0001-04000 | |
| | | Application Number | | | |
| Title of Invention | | METHODS OF GENERATING ENERGETIC PARTICLES USING NANOTUBES AND ARTICLES THEREOF | | | |
| Citizenship under 37 CFR 1.41(b) | | US | | | |
| Mailing Address of Applicant: | | | | | |
| Address 1 | | 224 E. Buena Vista | | | |
| Address 2 | | | | | |
| City | Santa Fe | | State/Province | NM | |
| Postal Code | 87505 | | Country | US | |
| All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the Add button. Add | | | | | |

Correspondence Information:

| | | | |
|---------------------------------------------------------------------------------------------------------------------------------------|-------|------------------------|---------------------------|
| Enter either Customer Number or complete the Correspondence Information section below. For further information see 37 CFR 1.33(a). | | | |
| <input type="checkbox"/> An Address is being provided for the correspondence Information of this application. | | | |
| Customer Number | 68540 | | |
| Email Address | | Add Email | Remove Email |

Application Information:

| | | | |
|-----------------------------------------|--------------------------------------------------------------------------------|-------------------------------------------|-------------------------------------|
| Title of the Invention | METHODS OF GENERATING ENERGETIC PARTICLES USING NANOTUBES AND ARTICLES THEREOF | | |
| Attorney Docket Number | 1112.0001-04000 | Small Entity Status Claimed | <input checked="" type="checkbox"/> |
| Application Type | Nonprovisional | | |
| Subject Matter | Utility | | |
| Suggested Class (if any) | | Sub Class (if any) | |
| Suggested Technology Center (if any) | | | |
| Total Number of Drawing Sheets (if any) | 6 | Suggested Figure for Publication (if any) | |

Publication Information:

| |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <input type="checkbox"/> Request Early Publication (Fee required at time of Request 37 CFR 1.219) |
| <input type="checkbox"/> Request Not to Publish. I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application has not and will not be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing. |

Representative Information:

| | | | |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------|----------------------------------------------|---------------------------------------------------------|
| Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32). Enter either Customer Number or complete the Representative Name section below. If both sections are completed the Customer Number will be used for the Representative Information during processing. | | | |
| Please Select One: | <input checked="" type="radio"/> Customer Number | <input type="radio"/> US Patent Practitioner | <input type="radio"/> Limited Recognition (37 CFR 11.9) |

| | | | |
|-------------------------------------------|--------------------------------------------------------------------------------|------------------------|-----------------|
| Application Data Sheet 37 CFR 1.76 | | Attorney Docket Number | 1112.0001-04000 |
| | | Application Number | |
| Title of Invention | METHODS OF GENERATING ENERGETIC PARTICLES USING NANOTUBES AND ARTICLES THEREOF | | |
| Customer Number | 68540 | | |

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, or 365(c) or indicate National Stage entry from a PCT application. Providing this information in the application data sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78(a)(2) or CFR 1.78(a)(4), and need not otherwise be made part of the specification.

| | | | |
|--------------------------|--------------------|--------------------------|--------------------------|
| Prior Application Status | Pending | Remove | |
| Application Number | Continuity Type | Prior Application Number | Filing Date (YYYY-MM-DD) |
| | Continuation of | 12/898807 | 2010-10-06 |
| Prior Application Status | Abandoned | Remove | |
| Application Number | Continuity Type | Prior Application Number | Filing Date (YYYY-MM-DD) |
| 12/898807 | Continuation of | 12/258568 | 2008-10-27 |
| Prior Application Status | Abandoned | Remove | |
| Application Number | Continuity Type | Prior Application Number | Filing Date (YYYY-MM-DD) |
| 12/258568 | Continuation of | 11/633524 | 2006-12-05 |
| Prior Application Status | Abandoned | Remove | |
| Application Number | Continuity Type | Prior Application Number | Filing Date (YYYY-MM-DD) |
| 11/633524 | non provisional of | 60/741874 | 2005-12-05 |
| Prior Application Status | Expired | Remove | |
| Application Number | Continuity Type | Prior Application Number | Filing Date (YYYY-MM-DD) |
| | | 60/777577 | 2006-03-01 |

Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button.

Foreign Priority Information:

This section allows for the applicant to claim benefit of foreign priority and to identify any prior foreign application for which priority is not claimed. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55(a).

| | | | |
|------------------------|----------------------|---------------------------------|----------------------------------------------------|
| Remove | | | |
| Application Number | Country ¹ | Parent Filing Date (YYYY-MM-DD) | Priority Claimed |
| | | | <input type="radio"/> Yes <input type="radio"/> No |

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button.

Assignee Information:

Providing this information in the application data sheet does not substitute for compliance with any requirement of part 3 of Title 37 of the CFR to have an assignment recorded in the Office.

| |
|------------------------------------------------------------------------------------|
| Assignee 1 |
| If the Assignee is an Organization check here. <input checked="" type="checkbox"/> |

| | | | |
|-------------------------------------------|--------------------------------------------------------------------------------|------------------------|-----------------|
| Application Data Sheet 37 CFR 1.76 | | Attorney Docket Number | 1112.0001-04000 |
| | | Application Number | |
| Title of Invention | METHODS OF GENERATING ENERGETIC PARTICLES USING NANOTUBES AND ARTICLES THEREOF | | |

| | | | |
|------------------------------------------------------------------------------------------------|--------------------------|----------------|-------|
| Organization Name | SELDON TECHNOLOGIES, LLC | | |
| Mailing Address Information: | | | |
| Address 1 | 7 EVERETT LANE | | |
| Address 2 | | | |
| City | WINDSOR | State/Province | VT |
| Country | US | Postal Code | 05089 |
| Phone Number | | Fax Number | |
| Email Address | | | |
| Additional Assignee Data may be generated within this form by selecting the Add button. | | | |

Signature:

| | | | | | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|-----------|--------|---------------------|------------|
| A signature of the applicant or representative is required in accordance with 37 CFR 1.33 and 10.18. Please see 37 CFR 1.4(d) for the form of the signature. | | | | | |
| Signature | /Louis Troilo, Reg. No. 45,284/ | | | Date (YYYY-MM-DD) | 2012-08-21 |
| First Name | Louis | Last Name | Troilo | Registration Number | 45284 |

This collection of information is required by 37 CFR 1.76. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 23 minutes to complete, including gathering, preparing, and submitting the completed application data sheet form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C. 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether the Freedom of Information Act requires disclosure of these records.
2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspections or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

UNITED STATES PATENT APPLICATION

FOR

**METHODS OF GENERATING ENERGETIC PARTICLES USING
NANOTUBES AND ARTICLES THEREOF**

BY

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[001] This application claims the benefit of domestic priority under 35 USC §119(e) to U.S. Application Nos. 60/741,874, filed December 5, 2005, and 60/777,577, filed March 1, 2006, both of which are incorporated by reference herein.

[002] Disclosed herein are methods of generating energetic particles, by contacting nanotubes with hydrogen isotopes in the presence of activation energy, such as thermal, electromagnetic, or the kinetic energy of particles. Also disclosed are methods of transmuting matter by exposing such matter to the energetic particles produced according to the disclosed method.

[003] A need exists for alternative energy sources to alleviate our society's current dependence on hydrocarbon fuels without further impact to the environment. The inventors have developed multiple uses for nanotubes and devices that use such nanotubes. The present disclosure combines the unique properties of nanotubes and in one embodiment carbon nanotubes, in a novel manifestation designed to meet current and future energy needs in an environmentally friendly way.

[004] Devices powered with nanotube based nuclear power systems may substantially change the current state of power distribution. For example, nanotube based nuclear power systems may reduce, if not eliminate, the need for power distribution networks; chemical batteries; energy scavenger devices such as solar cells, windmills, hydroelectric power stations; internal combustion, chemical rocket, or turbine engines; as well as all other forms of chemical combustion for the production of power.

SUMMARY OF THE INVENTION

[005] Accordingly, there is disclosed a method of generating energetic particles, which comprises contacting nanotubes with hydrogen isotopes and applying activation energy to the nanotubes. In one embodiment, the hydrogen isotopes comprises protium, deuterium, tritium, and combinations thereof. In addition, the source of hydrogen isotopes may be in a solid, liquid, gas, plasma, or supercritical phase. Alternatively, the source of hydrogen isotopes may be bound in a molecular structure.

[006] There is also disclosed a method of transmuting matter that comprises contacting nanotubes with a source of hydrogen isotopes, applying activation energy to the nanotubes, producing energetic particles, and contacting the matter to be transmuted with the energetic particles. As used herein, transmutable matter is matter that is transformed from one element or isotope to another element or isotope.

BRIEF DESCRIPTION OF THE DRAWINGS

[007] Fig. 1 is a schematic of a rotator type reactor for a liquid phase reaction with a He^3 detector used according to the present disclosure.

[008] Fig. 2 is a schematic of a rotator type according to Fig. 1, wherein the He^3 detector has been replaced with an array of Germanium detectors.

[009] Fig. 3 is a schematic of a reactor without a separate electrode for electrolysis of the liquid phase used according to the present disclosure.

[0010] Fig. 4 is a schematic of a reactor according to Fig. 3, further including a separate electrode for electrolysis of the liquid phase.

[0011] Fig. 5 is a schematic of a reactor for a gas phase reaction used according to the present disclosure.

[0012] Fig. 6 is a plot of the number of energetic particles generated using the reactor of Fig. 4.

DETAILED DESCRIPTION OF THE INVENTION

A. Definitions

[0013] The following terms or phrases used in the present disclosure have the meanings outlined below:

[0014] The term "fiber" or any version thereof, is defined as a high aspect ratio material. Fibers used in the present disclosure may include materials comprised of one or many different compositions.

[0015] The term "nanotube" refers to a tubular-shaped, molecular structure generally having an average diameter in the inclusive range of 25Å to 100nm. Lengths of any size may be used.

[0016] The term "carbon nanotube" or any version thereof refers to a tubular-shaped, molecular structure composed primarily of carbon atoms arranged in a hexagonal lattice (a graphene sheet) which closes upon itself to form the walls of a seamless cylindrical tube. These tubular sheets can either occur alone (single-walled) or as many nested layers (multi-walled) to form the cylindrical structure.

[0017] The phrase "environmental background radiation" refers to ionizing radiation emitted from a variety of natural and artificial sources including terrestrial sources and cosmic rays (cosmic radiation).

[0018] The term "functionalized" (or any version thereof) refers to a nanotube having an atom or group of atoms attached to the surface that may alter the properties of the nanotube, such as zeta potential.

[0019] The term "doped" carbon nanotube refers to the presence of ions or atoms, other than carbon, into the crystal structure of the rolled sheets of hexagonal carbon. Doped carbon nanotubes means at least one carbon in the hexagonal ring is replaced with a non-carbon atom.

[0020] The terms "transmuting," "transmutation" or derivatives thereof is defined as a change of the state of the nucleus, whether its changing the number of protons or neutrons in the nucleus or changing the energy in the nucleus through capture or emission of a particle. Transmuting matter is thus defined as changing the state of the nucleus comprising the matter.

[0021] In one embodiment, there is disclosed a method of producing energetic particles from the transmutation of isotopes utilizing a nanotube structure. In this embodiment, transmutation is a change to the nuclear composition of an isotope accompanied by a release or adsorption of energy. In order to generate energy from the combination or division of stable isotopes the addition of activation energy may be required.

[0022] This activation energy may come in the form of electromagnetic stimulation either directly or indirectly which imparts momentum temperatures, pressure or electromagnetic fields to the isotope. The initial activation energy may be in the form of a current pulse or electromagnetic radiation. Furthermore,

activation energy may come in the form of energy produced from the transmutation reactions described herein, also known as a chain reaction.

[0023] In certain isotopic transmutation reactions, activation energy is the energy required to overcome the coulomb repulsion that arises when two nuclei are brought close together. The primary isotope for such a reaction is deuterium (^2H), although hydrogen (^1H), tritium (^3H), and helium three (^3He) can also be used on the way to producing energy and helium four (^4He). Included by reference is a list of isotopes which can be used for energy producing transmutation reactions and can found on 507-521 of "Modern Physics" by Hans C. Ohanian 1987, which pages are herein incorporated by reference.

[0024] In order to overcome the coulomb repulsion of the isotopes required for transmutation, activation energy may be supplied in the form of thermal, electromagnetic, or the kinetic energy of a particle. Electromagnetic energy comprises one or more sources chosen from x-rays, optical photons, α , β , or γ -rays, microwave radiation, infrared radiation, ultraviolet radiation, phonons, cosmic rays, radiation in the frequencies ranging from gigahertz to terahertz, or combinations thereof.

[0025] The activation energy may also comprise particles with kinetic energy, which are defined as any particle, such as an atom or molecule, in motion. Non-limiting embodiments include protons, neutrons, anti-protons, elemental particles, and combinations thereof. As used herein, "elemental particles" are fundamental particles that cannot be broken down to further particles. Examples of elemental particles include electrons, anti-electrons, mesons, pions, hadrons, leptons (which is a form of electron), baryons, radio isotopes, and combinations thereof.

[0026] Other particles that may be used as activation energy in the disclosed method include those mentioned by reference at pages 460-494 of "Modern Physics" by Hans C. Ohanian, which pages are herein incorporated by reference.

[0027] Similarly, the energetic particles generated by the disclosed method may comprise the same energetic particles previously described, namely neutrons, protons, electrons, beta radiation, alpha radiation, mesons, pions,

hadrons, leptons, baryons, and combinations thereof. In other words, the energetic particles produced by the disclosed method may comprise the same energetic particles used to initiate the reaction.

[0028] Because energy production required for the transmutation reaction described herein uses activation energy, one can control the energy produced by controlling the amount of activation energy present or the rate at which the isotopes are being fed in the inventive process to the nanotube structure. For example, the generation of energy can be significantly reduced by freezing a nanotube/heavy water mixture, thus robbing thermal energy from the nuclear transmutation process and slowing diffusion of deuterium into the nanotubes, such as carbon nanotubes.

[0029] In one embodiment, transmuting matter may be accomplished by contacting matter with a nanotube structure, confining the matter within a dimension of the nanotube structure, and exposing the nanotube structure with the matter confined therein to activation energy.

[0030] Without being bound by any theory the methods for generation of energetic particles and transmutation reactions described herein are a manifestation, at least in part, to the nanotube structure. It is believed that when matter on the atomic scale is confined to the limited dimensions of a nanotube structure, the nucleus of the atoms comprising the matter will more likely be subject to interaction and thus transmutation of the matter. In other words, nanoscale confinement increases the probabilities that nuclei of matter will interact. Similar theories have been described as screening in a one-dimensional Bose gas, a description of which can be found in the article by N.M. Bogolyubov et al., *Complete Screening in a One-Dimensional Bose Gas*, Zapiski Nauchnykh Seminarov Leningradskogo Otdeleniya Matematicheskogo Instituta im. V.A. Steklova AN SSSR, Vol. 150 pp. 3-6, 1986.

[0031] Thus, in one embodiment, it is believed that with a high density electron plasma inside the confined system of a carbon nanotube when a current, such as in the form of a pulse, is applied to the carbon nanotube, and in the presence of deuterium, coulomb repulsion may be reduced or eliminated. Electrons may be in very close proximity to the nuclei, thus on average canceling

out the coulomb repulsion between deuterium isotopes. This in turn should decrease the required activation energy for transmutation.

[0032] Any nanoscaled structure having a hollow interior that assists or enables nanoscale confinement, and that is capable of withstanding the internal conditions associated with the disclosed method, can be used in the disclosed process.

[0033] In one embodiment, the nanotubes comprises carbon and its allotropes. For example, the carbon nanotube used according to the present disclosure may comprise a multi-walled carbon nanotube having a length ranging from $500\mu\text{m}$ to 10cm , such as from 2mm to 10mm . Nanotube structures according to the present disclosure may have an inside diameter ranging up to 100nm , such as from 25Å to 100nm .

[0034] The nanotube material may also comprise a non-carbon material, such as an insulating, metallic, or semiconducting material, or combinations of such materials.

[0035] It is to be appreciated that the hydrogen isotopes may be located within the interior of a nanotube, the space between the walls of a multi-walled nanotube (when used), inside at least one loop formed by one or more nanotubes, or combinations thereof.

[0036] In one embodiment, the nanotubes may be aligned end to end, parallel, or in any combination thereof. In addition, or alternatively, the nanotubes may be fully or partially coated or doped by least one atomic or molecular layer of an inorganic material.

[0037] In certain embodiments, the methods of transmuting matter may be enhanced when the nanotube structure catalytically interacts with the matter confined therein. This may be done by either choosing a particular nanotube, such as carbon, or by doping or coating the nanotube with a molecule that can alter the amount or type of activation energy needed to initiate the disclosed reactions.

[0038] As used herein, "catalyst" any word derived therefrom, is defined as a substance that changes the activation energy. In one embodiment, changing

the activation energy is defined as lowering the energy required for transmutation reaction(s) to occur.

[0039] When the nanotube structure further acts as a catalyst, it may do so as an integrator, taking many low energy photons, phonons or particles and additively delivering their energy to the transmutation nuclei. The previously mentioned forms of activation energy may also be used in such a process.

[0040] In some cases, activation energy may result from the sum of multiple forms of energy, such as x-rays nanotube capture coincident with electron nuclear scattering to drive the transmutation reaction, such as the transmutation of deuterium into ^3He and neutrons.

[0041] In certain embodiments, it is possible to produce a chain reaction by loading hydrogen isotopes within the nanotube so that energy released from one transmutation event will drive more transmutation events.

[0042] As stated, method of transmuting matter may lead to the generation of energy, from the release of energetic particles. In non-limiting embodiments, the energy generated from the disclosed method may comprise neutrons tritons, helium isotopes and protons with kinetic energy.

[0043] The nanotube structure disclosed herein may comprise single walled, double walled or multi-walled nanotubes or combinations thereof. The nanotubes may have a known morphology, such as those described in Applicants co-pending applications, including U.S. Patent Application 11/111,736, filed April 22, 2005, U.S. Patent Application No. 10/794,056, filed March 8, 2004 and U.S. Patent Application No. 11/514,814, filed September 1, 2006, all of which are herein incorporated by reference.

[0044] Some of the above described shapes are more particularly defined in M.S. Dresselhaus, G. Dresselhaus, and P. Avouris, eds. Carbon Nanotubes: Synthesis, Structure, Properties, and Applications, *Topics in Applied Physics*. 80. 2000, Springer-Verlag; and "A Chemical Route to Carbon Nanoscrolls, Lisa M. Viculis, Julia J. Mack, and Richard B. Kaner; *Science*, 28 February 2003; 299, both of which are herein incorporated by reference.

[0045] When nanotube structures having the foregoing morphologies are employed, the confinement dimension, defined as the dimension in which the

matter undergoing transmutation is confined, is chosen from the interior of a nanotube, the space between the walls of a multi-walled nanotube, inside at least one loop formed by one or more nanotubes, or combinations thereof.

[0046] As previously stated, the method according to the present disclosure typically uses an activation energy to assist in transmutation. Non-limiting examples of such activation energy includes microwave radiation, infrared radiation, thermal energy, phonons, optical photons, ultraviolet radiation, x-rays, γ -rays, α -radiation, β -radiation, and cosmic rays.

[0047] It is understood that the nanotube structure may comprise a network of nanotubes which are optionally in a magnetic, electric, or otherwise electromagnetic field. In one non-limiting embodiment, the magnetic, electric, or electromagnetic field can be supplied by the nanotube structure itself.

[0048] In addition, the method may further include applying an alternating current direct current or current pulses to the nanotube structure or combinations thereof.

[0049] The nanotube structure disclosed herein may have a epitaxial layers of metals or alloys.

[0050] The composition of the nanotube is not known to be critical to the methods described herein. Without being bound by theory, it appears that the confinement of the species within the nanotube may be responsible for the effects that are disclosed herein, rather than some interaction of the carbon in the nanotubes used in the disclosed embodiment and the species that was energized by the confinement, deuterium. For this reason, while the nanotubes describe herein are specifically described as carbon, more generally, they can comprise ceramic (including glasses), metallic (and their oxides), organic, and combinations of such materials.

[0051] The morphology (geometric configuration) of the nanotubes, other than providing confinement in a dimension for the species being energized, is not known to be critical. In one embodiment, there is disclosed a multi-walled, carbon nanotube. The nanotube structure disclosed herein may have single or multiple atomic or molecular layers forming a shell or coating on the nanotubes

described herein. In addition to such coatings, the nanotube structure may be doped by least one atomic or molecular layer of an inorganic or organic material.

[0052] A description of coatings for nanotubes, as well as methods of coating nanotubes, are described in applicants co-pending application, which were previously incorporated by reference, i.e., U.S. Patent Application 11/111,736, filed April 22, 2005, U.S. Patent Application No. 10/794,056, filed March 8, 2004 and U.S. Patent Application No. 11/514,814, filed September 1, 2006.

[0053] The method described herein may further comprise functionalizing the carbon nanotubes with at least one organic group. Functionalization is generally performed by modifying the surface of carbon nanotubes using chemical techniques, including wet chemistry or vapor, gas or plasma chemistry, and microwave assisted chemical techniques, and utilizing surface chemistry to bond materials to the surface of the carbon nanotubes. These methods are used to "activate" the carbon nanotube, which is defined as breaking at least one C-C or C-heteroatom bond, thereby providing a surface for attaching a molecule or cluster thereto.

[0054] Functionalized carbon nanotubes may comprise chemical groups, such as carboxyl groups, attached to the surface, such as the outer sidewalls, of the carbon nanotube. Further, the nanotube functionalization can occur through a multi-step procedure where functional groups are sequentially added to the nanotube to arrive at a specific, desired functionalized nanotube.

[0055] Unlike functionalized carbon nanotubes, coated carbon nanotubes are covered with a layer of material and/or one or many particles which, unlike a functional group, is not necessarily chemically bonded to the nanotube, and which covers a surface area of the nanotube.

[0056] Carbon nanotubes used herein may also be doped with constituents to assist in the disclosed process. As stated, a "doped" carbon nanotube refers to the presence of ions or atoms, other than carbon, into the crystal structure of the rolled sheets of hexagonal carbon. Doped carbon nanotubes means at least one carbon in the hexagonal ring is replaced with a non-carbon atom.

[0057] Also disclosed is a method of transmuting matter that comprises contacting nanotubes with a source of hydrogen isotopes, applying activation energy to the nanotubes, producing energetic particles, and contacting the matter to be transmuted with the energetic particles.

[0058] A fraction of the energy produced from transmutation in the form of radiation may be used directly to drive second generation transmutation reactions. This method can be used to continually generate power to the levels required for consumption.

[0059] In one embodiment, the method described herein may be used to transmute isotopes having a long half-life and considered to be radioactive pollutants into isotopes with a shorter half-life. This may be accomplished via neutron capture. In this embodiment, it may be desirable to feed the nanotube with deuterium since many neutrons packed closely together in the carbon nanotubes can be captured by the target isotope. The abundance of neutrons in the nucleus will drive transmutation reactions, this reducing the half-life of a radioactive isotope from hundreds or thousands of years to milliseconds.

[0060] In another embodiment, the transmutation of deuterium into ^3He and neutrons may be performed by contacting carbon nanotubes with a deuterium gas and activation energy. In this embodiment, the deuterium is kept in high concentration by a confinement vessel that surrounds the element components, e.g., the deuterium gas, the carbon nanotubes, and attached electrodes. In addition, the carbon nanotubes should be bundled to make electrical contact with the electrodes at either end of the bundle. Wires are attached to the electrode and feed the carbon nanotubes with activation energy from a circuit that produces a 400V pulse for 10ns. A schematic of this embodiment is shown in Fig. 5.

[0061] The present disclosure is further illustrated by the following non-limiting examples, which are intended to be purely exemplary of the disclosure.

EXAMPLES

Example 1. Production of Energetic Particles Using Treated Carbon Nanotubes

a) Production of Carbon Nanotube Material

[0062] 5g of carbon nanotubes were mixed with 250 ml of reagent grade nitric acid at room temperature. The carbon nanotubes were multi-walled, with diameters ranging from 10nm to 50nm and lengths ranging from 100 nm to 100um. After 20 minutes, the carbon nanotubes were removed from the nitric acid and washed with water three times. The carbon nanotubes were dried in an oven set above room temperature to remove water. From that batch, 100 mg of the carbon nanotubes were combined with 35-40 ml of 99.9% pure D₂O in a 50 ml glass beaker (Sample A). The D₂O was taken from a new 250 gram sample that was purchased from Sigma Aldrich (Part number 151882-250G, Batch number 08410KC).

b) Measurements on Carbon Nanotube Material

[0063] Various energetic particles emitted from Sample A were measured in the following manner:

[0064] Sample A was covered with clear plastic wrap to minimize evaporation of the D₂O and water absorption into the hygroscopic D₂O. It was then placed in a rotatable sample holder, which was held at a 45 degree angle relative to the floor and rotated at about 1 rpm during measurement so as to keep the surface carbon nanotubes at least partially wet. A schematic of this rotating sample holder is shown in Fig. 1.

[0065] Energy above background was measured using a ³He Neutron detector and a NaI (sodium iodide) gamma/x-ray detector. Background measurements were made with no sample present. Sample A was initially measured in a dark room. The measurement was repeated with the sample irradiated by a UV filtered halogen light. A second sample (B), identical in composition and morphology to sample A was prepared. Sample B was irradiated separately with (a) a UV filtered halogen light and (b) a red laser.

[0066] While all samples, including that measured in the dark room, showed a positive bias above background, enhanced signal was noticed when a

light source was used, with the strongest response occurring for the UV filtered halogen light.

[0067] This example shows that by combining treated carbon nanotubes with D₂O, energetic particles were produced.

Example 2. Production of Energetic Particles Using Untreated Carbon Nanotubes

a) Production of Carbon Nanotube Material

[0068] This example was substantially similar to Ex. 1, with the exception that untreated multi-walled carbon nanotubes were used in this example. The carbon nanotubes had diameters ranging from 10nm to 50nm and lengths ranging from 100 nm to 100um. About 100 mg of the carbon nanotubes were combined with 35-40 ml of 99.9% pure D₂O in a 50 ml glass beaker.

b) Measurements on Carbon Nanotube Material

[0069] Energetic particles emitted from the sample made according to this invention were measured in the following manner:

[0070] As in Example 1, the sample according to this example was covered with clear plastic wrap to minimize evaporation of the D₂O and water absorption into the hygroscopic D₂O. It was then placed in a rotatable sample holder, which was held at a 45 degree angle relative to the floor and rotated at about 1 rpm during measurement so as to keep the surface carbon nanotubes at least partially wet.

[0071] A schematic of the set-up used in this Example is shown in Fig. 2, which is similar to Fig. 1, with the ³He detector being replaced by an array of Germanium detectors. In particular, prior to the application of the activation energy, two arrays of Germanium neutron detectors, placed on either side of the apparatus, were calibrated to determine the background rate of neutrons at the site of the experiment. The detectors were state of the art neutron detectors that were the property of the Lawrence Livermore National Laboratories and the manner in which the detectors operated was proprietary to their owners.

[0072] Background measurements were made with no sample present. The measurement was made while the sample was irradiated by a UV filtered

halogen light. While all measurements including background showed a positive bias above background, enhanced signal was noticed when the UV filtered halogen light was applied.

[0073] This example shows that by combining untreated carbon nanotubes with D₂O, while applying activation energy, energetic particles were produced.

Example 3. Production of Energetic Particles Via Transmutation in a Liquid Phase - Without An Electrolysis Electrode

[0074] In this example the nanotubes were commercially pure carbon nanotubes obtained from NanoTechLabs (NanoTechLabs Inc., 409 W. Maple St., Yadkinville, NC 27055). They had a length of approximately 3mm, with a 6 member ring structure and were straight in orientation. The carbon nanotubes were substantially defect free and were not treated prior to use in the device.

[0075] A bundle of aligned carbon nanotubes containing approximately 1,000 individual nanotube was connected to stainless steel electrodes at each end of the bundle. The carbon nanotube electrode system was measured to have approximately 200Ω of resistance. One nanotube electrode was connected through a capacitor to ground and to a 19.5Ω resistor connected to the high voltage supply. See Fig. 3. The other nanotube electrode was connected through a 30ns rise time transistor to ground. The gate on the transistor was connected to a pulse generator.

[0076] The carbon nanotube electrode system was submerged in 2 grams of liquid D₂O in a ceramic reactor boat at room temperature and pressure. A voltage was applied to the carbon nanotubes as a 200 Volt spike for a duration in the range of from 200 nanoseconds at a repetition rate of approximately 10KHz.

[0077] A signal generator delivered a 150ns wide pulse at 9V to the transistor to trigger the discharge of the capacitor through the deuterium loaded carbon nanotubes. Neutron bursts were produced for a 2hr time period before the stainless steel electrodes corroded due to electro corrosion and no longer made contact with the carbon nanotubes. The data acquisition system recorded data above background for this time period.

[0078] Prior to the application of the voltage two arrays of Germanium neutron detectors, placed on either side of the apparatus, were calibrated to determine the background rate of neutrons at the site of the experiment. The detectors were state of the art neutron detectors that were the property of the Lawrence Livermore National Laboratories and the manner in which the detectors operated was proprietary to their owners.

[0079] Prior to the application of voltage, the detectors intermittently detected neutron with no observed periodicity of detections. This was comparable to background radiation. After the voltage was applied to the carbon nanotube again the detectors detected neutrons intermittently. The neutrons were detected in short duration bursts and as a low level steady stream above background with the detection event being from four to 100 times the magnitude of the background detections. When the application of the voltage was discontinued the detections were again characteristic in magnitude of those at background levels and no periodicity of the bursts was observed. The kinetic energy of the detected neutron could not be measured with the equipment used.

[0080] The experimental apparatus had no provision for measuring any heat generated during the operation of the device. Nor was there any provision for testing the composition of gases that may have been created during the process.

Example 4. Production of Energetic Particles Via Transmutation in a Liquid Phase - With An Electrolysis Electrode

[0081] In this example the nanotubes were commercially pure carbon nanotubes obtained from NanoTechLabs (NanoTechLabs Inc., 409 W. Maple St., Yadkinville, NC 27055). They had a length of approximately 6mm, with a 6 member ring structure and were straight in orientation. The carbon nanotubes were substantially defect free and were not treated prior to use in the device.

[0082] A bundle of aligned carbon nanotubes containing approximately 1,000 individual nanotube was connected to platinum electrodes at each end of the bundle. The carbon nanotube electrode system was measured to have approximately 8Ω of resistance. One nanotube electrode was connected through

a capacitor to ground. The other nanotube electrode was connected through a transistor to ground. A third electrolysis electrode was held in close proximity to the center of the carbon nanotube bundle and was connected to a 490V 5mA power supply through a 6K Ω resistor. A schematic and description of this set-up is shown in Fig. 4.

[0083] The carbon nanotube electrode system was submerged in 2 grams of liquid D₂O in a ceramic reactor boat at room temperature and pressure. A voltage was applied to the carbon nanotubes as a 490 Volt spike for a duration in the range of from 10 to 100 nanoseconds at a repetition rate of approximately 730 Hz. During the millisecond the capacitor was charging, the charging current was also used to perform electrolysis of the D₂O to produce D₂ gas at the nanotube surface. Electrolysis was performed to increase diffusion of D₂ into the carbon nanotube. A signal generator delivered a 150ns wide pulse at 9V to the transistor to trigger the discharge of the capacitor through the deuterium loaded carbon nanotubes. Neutron bursts were produced and recorded by a data acquisition system that were not present in the background.

[0084] A plot of the number of energetic particles generated according to this example is shown in Fig. 6.

[0085] Prior to the application of the voltage two arrays of Germanium neutron detectors, placed on either side of the apparatus, were calibrated to determine the background rate of neutrons at the site of the experiment. The detectors were state of the art neutron detectors that were the property of the Lawrence Livermore National Laboratories and the manner in which the detectors operated was proprietary to their owners.

[0086] Prior to the application of voltage, the detectors intermittently detected neutron with no observed periodicity of detections. This was comparable to background radiation. After the voltage was applied to the carbon nanotube again the detectors detected neutrons intermittently. As shown in Fig. 6, the neutrons were detected in short duration bursts with the detection event being from four to ten thousand times the magnitude of the background detections. In addition, over time a periodicity of the bursts was observed, the frequency of which was approximately 10 minutes. When the application of the

voltage was discontinued the detections were again characteristic in magnitude of those at background levels and no periodicity of the bursts was observed. The kinetic energy of the detected neutron could not be measured with the equipment used.

[0087] The experimental apparatus had no provision for measuring any heat generated during the operation of the device. Nor was there any provision for testing the composition of gases that may have been created during the process. The composition of the liquid remaining after the experiment was determined and the amount of heavy water in the sample had decreased.

[0088] The data generated from this example was statistically analyzed via a Hurst analysis to determine the statistical significance of the results. A Hurst analysis is a correlated analysis of random and non-random occurrences of events yielding a figure of merit. A figure of merit centered around 0.5 indicates random data. A figure of merit approaching 1.0 indicates positive correlation. A figure of merit approaching zero indicates anti-correlation. Data according to this example approached 0.9 indicating high positive correlation. In other words, the statistical analysis of the data from this example provides strong evidence of non-random signal.

[0089] Unless otherwise indicated, all numbers expressing quantities of ingredients, reaction conditions, and so forth used in the specification and claims are to be understood as being modified in all instances by the term "about." Accordingly, unless indicated to the contrary, the numerical parameters set forth in the following specification and attached claims are approximations that may vary depending upon the desired properties sought to be obtained by the present invention.

[0090] Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with the true scope of the invention being indicated by the following claims.

What Is Claimed Is:

1. A method of generating energetic particles, said method comprising contacting nanotubes with hydrogen isotopes, and applying activation energy to said nanotubes.

2. The method of claim 1, wherein said hydrogen isotopes comprises protium, deuterium, tritium, and combinations thereof.

3. The method of claim 1, wherein said hydrogen isotopes are provided from a source that is in a solid, liquid, gas, plasma, or supercritical phase.

4. The method of claim 1, wherein said hydrogen isotopes are provided from a source that are bound in a molecular structure..

5. The method of claim 1, wherein hydrogen isotopes are provided via D₂O.

6. The method of claim 1, wherein said activation energy comprises thermal, electromagnetic, or the kinetic energy of a particle.

7. The method of claim 6, wherein said electromagnetic energy comprises one or more sources chosen from x-rays, optical photons, γ -rays, microwave radiation, infrared radiation, ultraviolet radiation, phonons, radiation in the frequencies ranging from gigahertz to terahertz, or combinations thereof.

8. The method of claim 6, wherein said particle containing kinetic energy is chosen from neutrons, protons, electrons, beta radiation, alpha radiation, mesons, pions, hadrons, leptons, baryons, and combinations thereof.

9. The method of claim 1, wherein said energetic particles comprise neutrons, protons, electrons, beta radiation, alpha radiation, mesons, pions, hadrons, leptons, baryons, and combinations thereof.

10. The method of claim 1, wherein said nanotubes comprise carbon nanotubes.

11. The method of claim 1, wherein said nanotube is a multi-walled carbon nanotube.

12. The method of claim 1, wherein said nanotube is a multi-walled carbon nanotube has a length ranging from 500 μ m to 10cm.

13. The method of claim 1, wherein said nanotube is a multi-walled carbon nanotube having a length ranging from 2mm to 10mm.

14. The method of claim 1, wherein said hydrogen isotopes are located within the interior of a nanotube, the space between the walls of a multi-walled nanotube, inside at least one loop formed by one or more nanotubes, or combinations thereof.

15. The method of claim 1, further comprising forming a bundle of carbon nanotubes and providing activation energy in the form of electrical energy, to the bundle.

16. The method of claim 13, wherein said electrical energy is in the form of an electrical pulse.

17. The method of claim 1, wherein said nanotubes are aligned end to end, parallel, or in any combination thereof.

18. The method of claim 1, wherein said nanotube structure has an inside diameter ranging up to 100nm.

19. The method of claim 1, wherein the said nanotube is comprised of insulating, metallic, or semiconducting materials and combinations of such materials.

20. The method of claim 1, wherein said nanotubes consist essentially of carbon and its allotropes.

21. The method of claim 1, further comprising at least partially coating or doping least one atomic or molecular layer of an inorganic material prior to applying said activation energy.

22. The method of claim 1, wherein said activation energy comprises environmental background radiation.

23. The method of claim 22, wherein said environmental background radiation comprises cosmic rays.

24. A method of transmuting matter, said method comprising contacting nanotubes with a source of hydrogen isotopes, applying activation energy to said nanotubes, producing energetic particles, and contacting the matter to be transmuted with said energetic particles.

ABSTRACT

There is disclosed a method of generating energetic particles, which comprises contacting nanotubes with a source of hydrogen isotopes, such as D₂O, and applying activation energy to the nanotubes. In one embodiment, the hydrogen isotopes comprises protium, deuterium, tritium, and combinations thereof. There is also disclosed a method of transmuting matter that is based on the increased likelihood of nuclei interaction for atoms confined in the limited dimensions of a nanotube structure, which generates energetic particles sufficient to transmute matter and exposing matter to be transmuted to these particles.

CARBON NANOTUBE TRANSMUTATION
WET-CELL

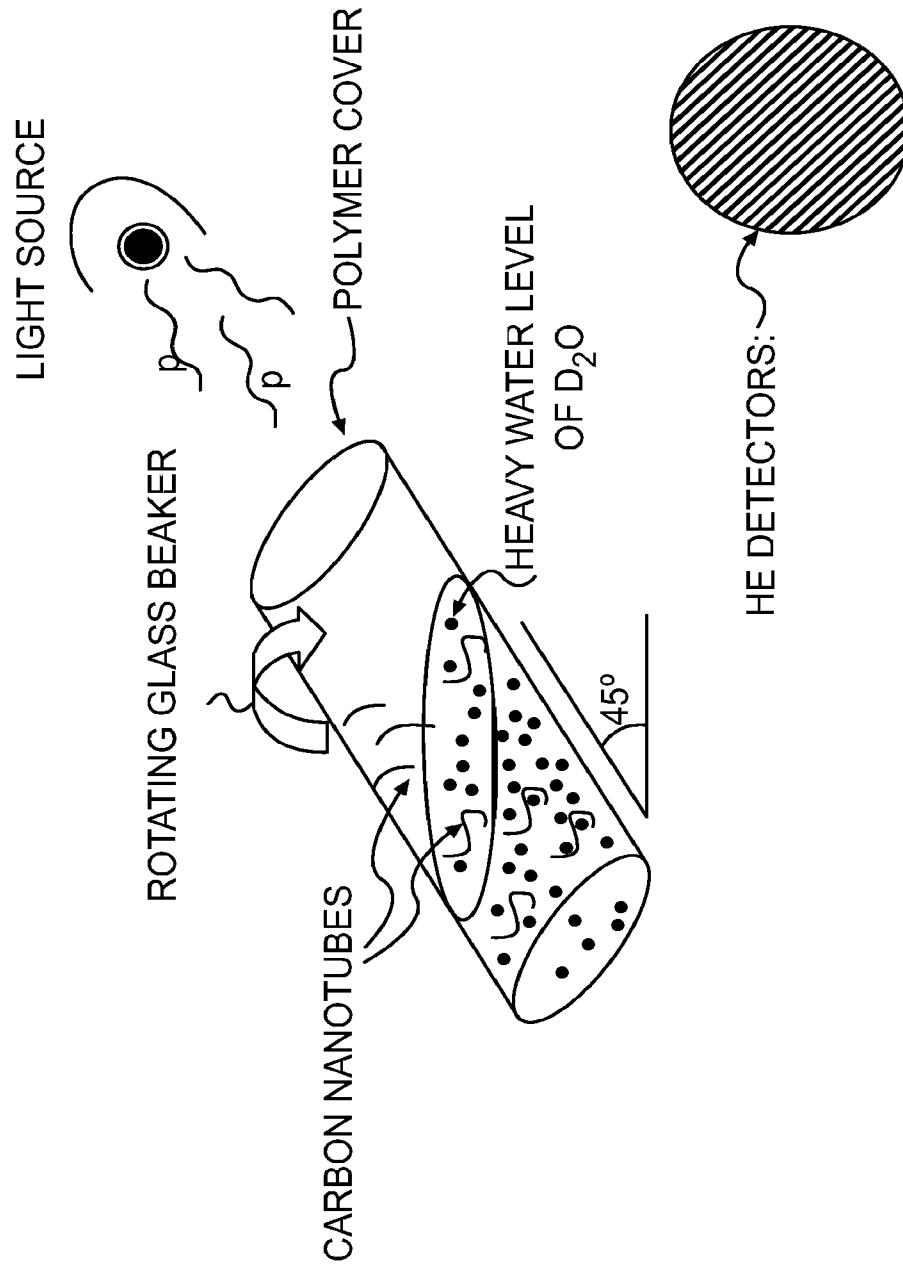


FIG. 1

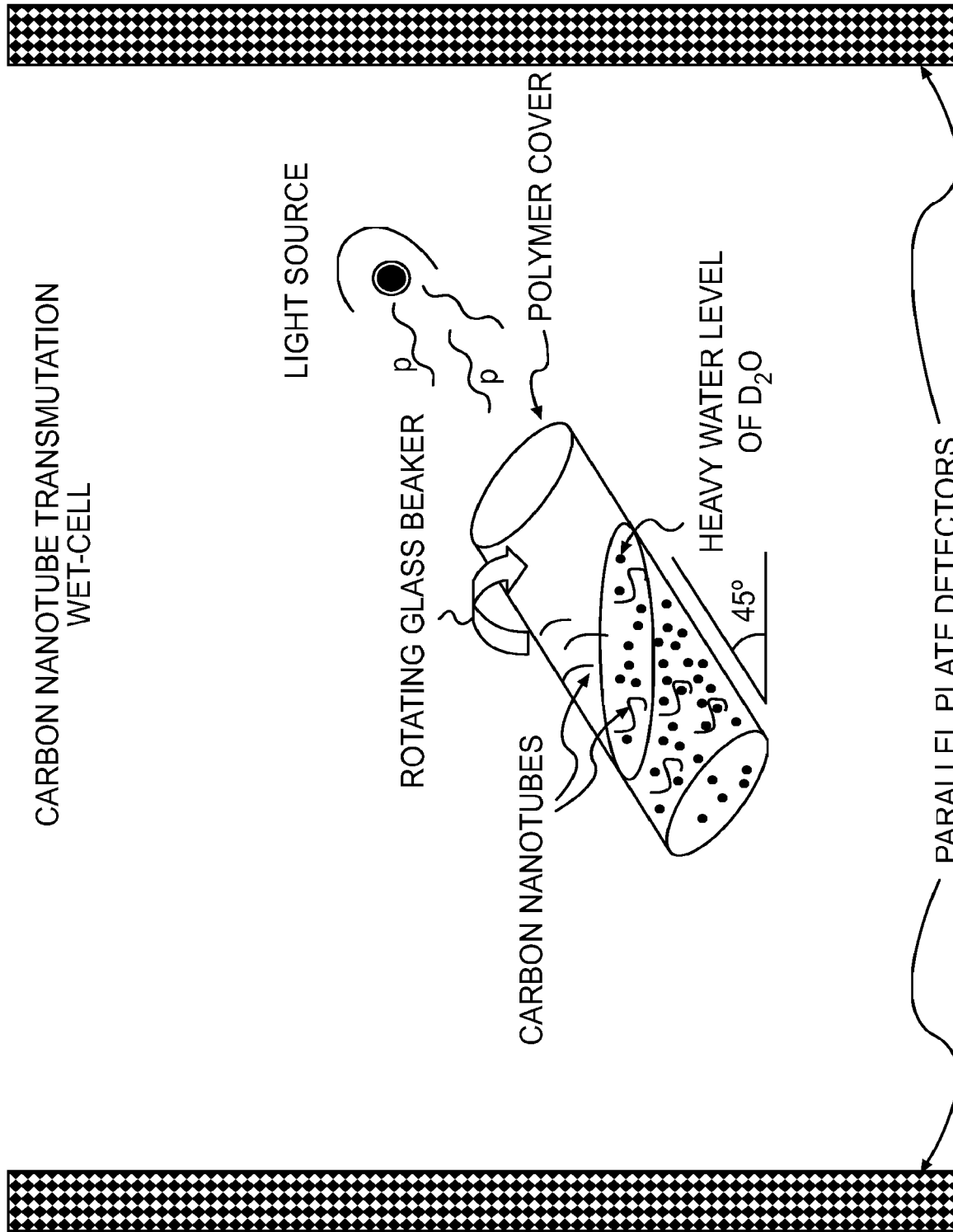


FIG. 2

CARBON NANOTUBE DEVICE FOR
PRODUCING ENERGETIC PARTICLES VIA TRANSMUTATION

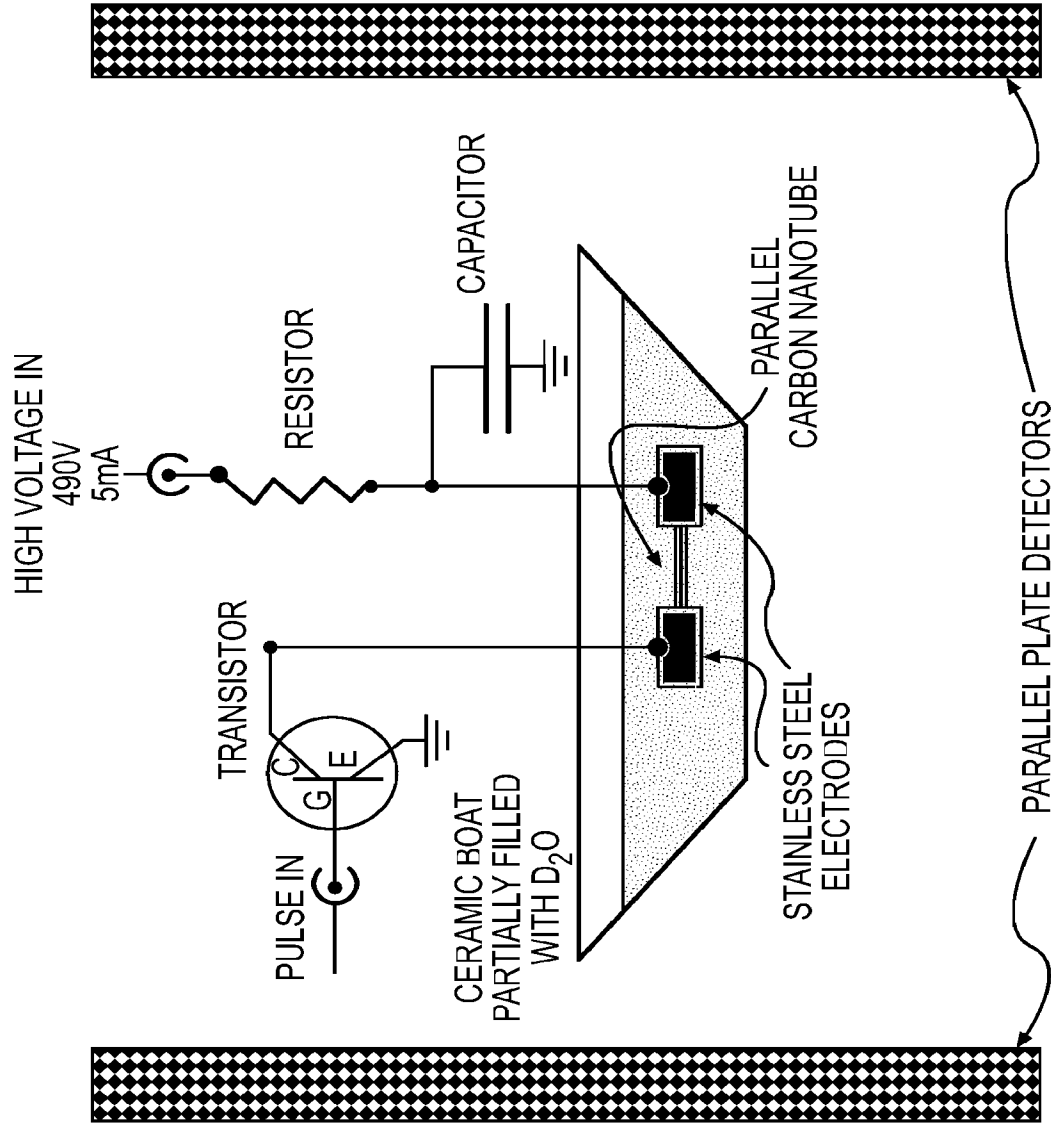


FIG. 3

CARBON NANOTUBE DEUTERIUM
TRANSMUTATION WET-CELL & DRIVING CIRCUIT

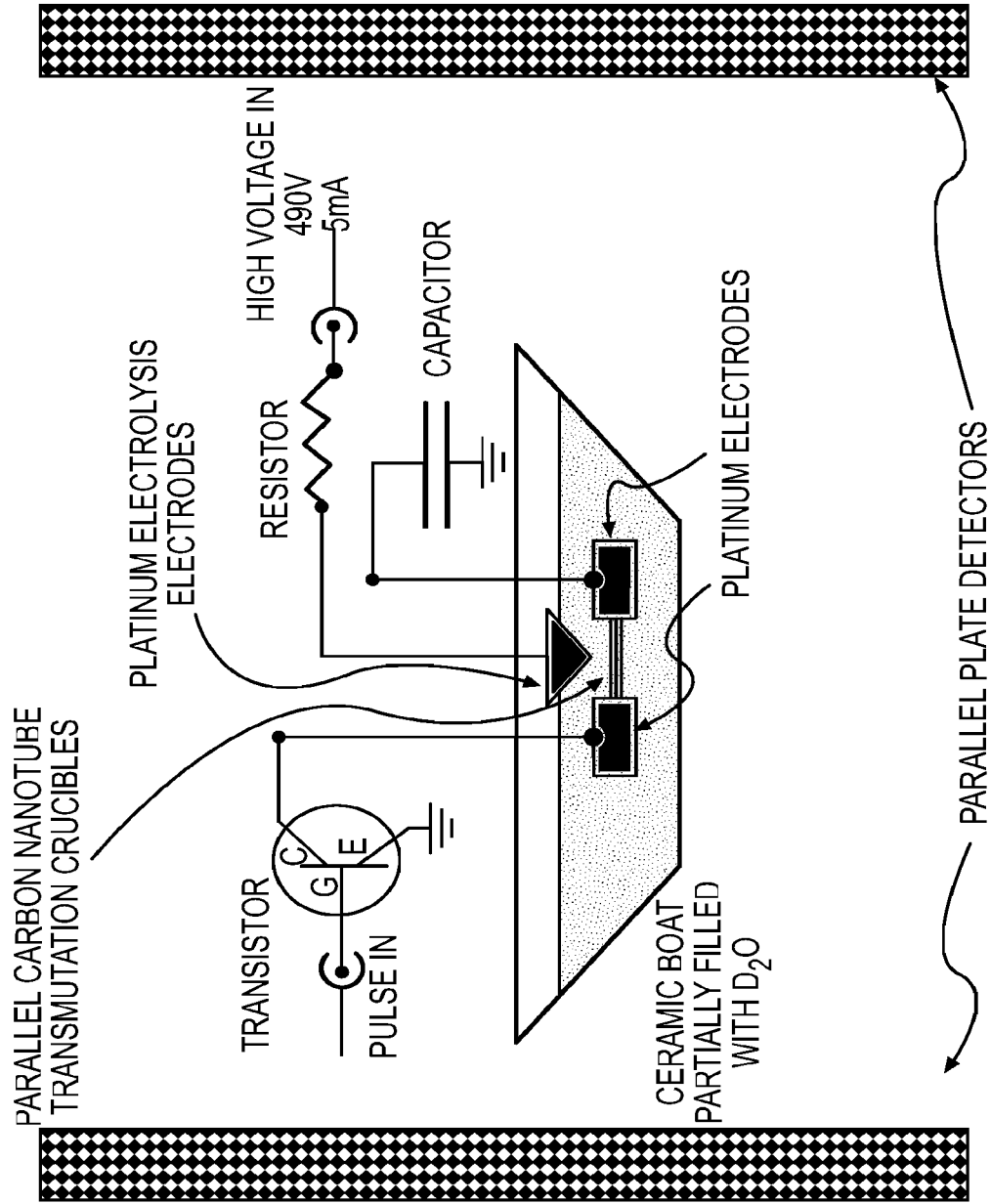
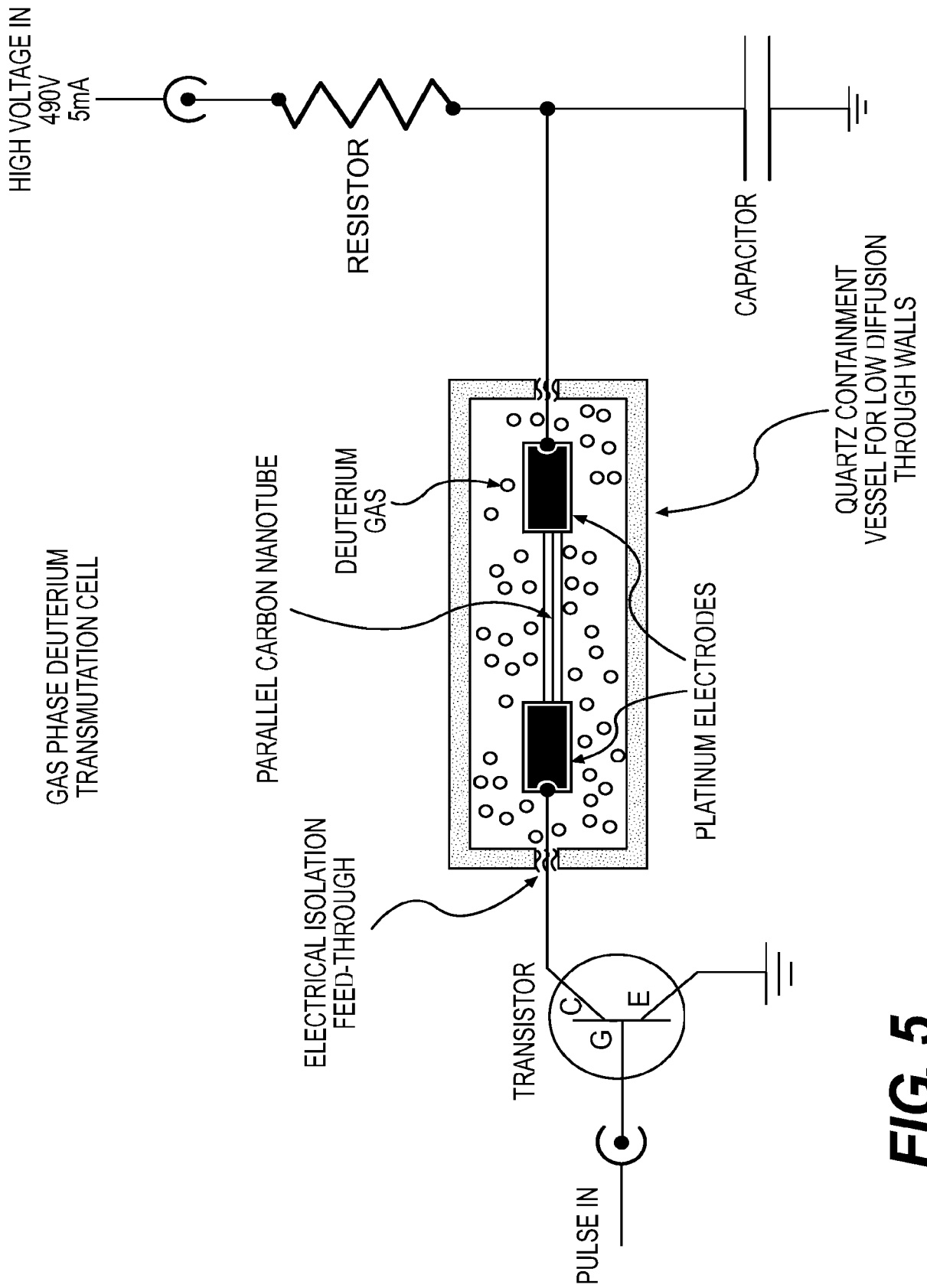


FIG. 4



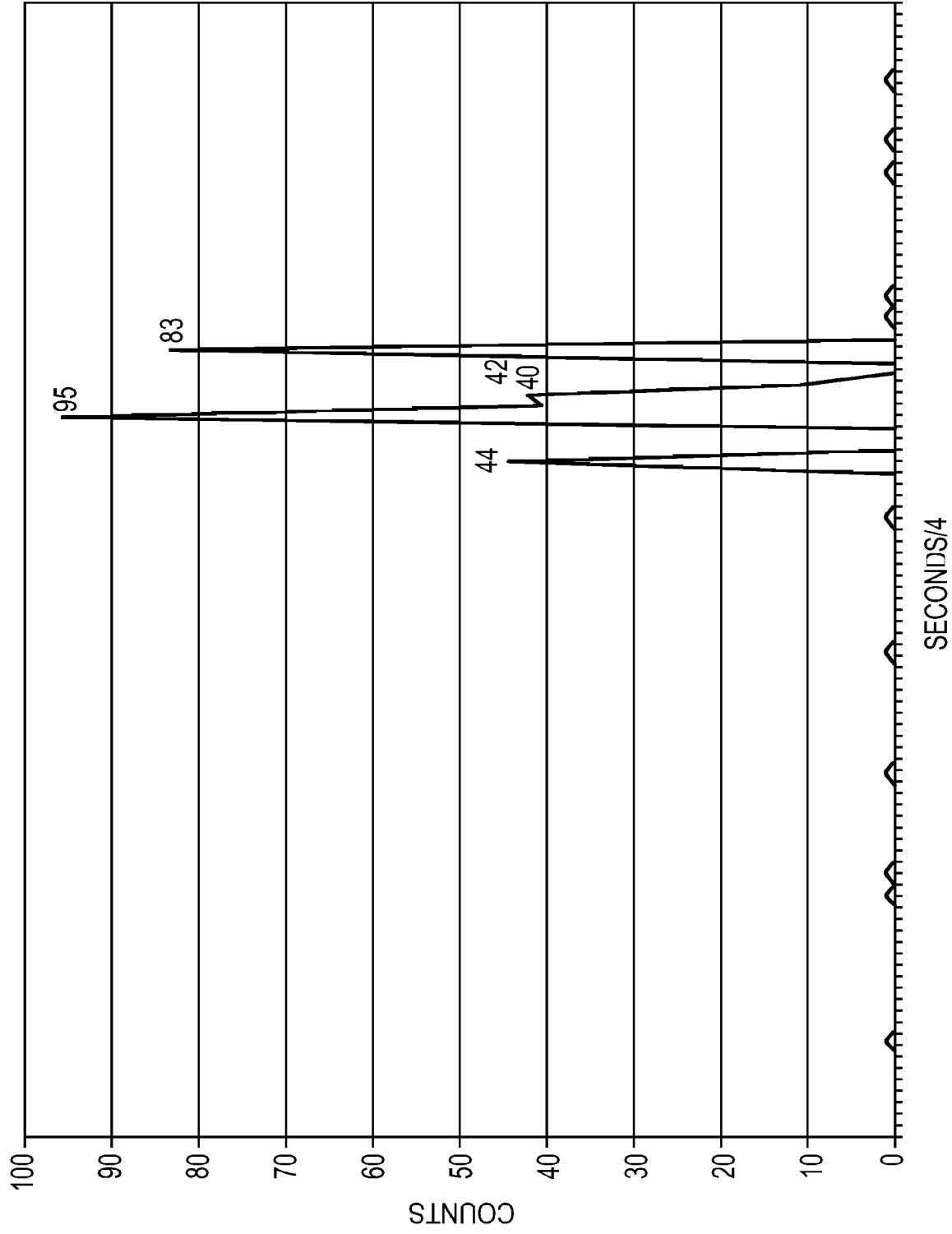


FIG. 6

DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that: my residence, post office address and citizenship are as stated below next to my name; I believe I am an original, first, and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled: METHODS OF GENERATING ENERGETIC PARTICLES USING NANOTUBES AND ARTICLES THEREOF the specification of which was filed on December 5, 2006 as United States Application No. 11/633,524 and Confirmation No. 2236, a copy of which is attached hereto.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims. I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56.


I hereby claim the benefit under 35 U.S.C. § 119(e) of the United States provisional applications listed below:

| Application Number | Date of Filing |
|--------------------|------------------|
| 60/741,874 | December 5, 2005 |
| 60/777,577 | March 1, 2006 |

I hereby appoint the patent practitioners associated with **FINNEGAN, HENDERSON, FARABOW, GARRETT & DUNNER, L.L.P., CUSTOMER NUMBER 22,852** to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

| | | |
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