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Provisional Application for Patent Cover Sheet

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GAS-PHASE IONIZING RADIATION GENERATOR

ABSTRACT

This invention describes a method and means to utilize one or more specially prepared and activated working electrodes in whole or in part of hydriding materials that are not normally considered to be radioactive and a gas or vapor containing hydrogen and/or its isotopes to produce at least one or more of multiple forms of ionizing radiation such as photons, (UV, x-ray or gamma), and particles, (alpha, beta, proton, triton, or positron).

SUMMARY OF THE INVENTION

This invention encompasses a novel method and means to produce at least one or more multiple forms of radiation such as photons including visible, UV, x-ray and gamma, and particles including alphas, electrons, beta minus, beta plus, protons, tritons, and neutrons by using a gas or vapor containing hydrogen and/or its isotopes and specially prepared and activated working electrodes comprised of materials that may not be naturally radioactive. As used herein, the term "hydrogen" may include its isotopes deuterium and tritium and ions thereof. Another feature of this invention is the ability to generate ionizing radiation and to ionize gas at significantly lower energies than required by current art methods. Both the ionizing radiation and particles and the ionized gas that can be produced have many applications. One of the many

applications is to use the ionizing radiation to ionize gas and produce a weakly ionized or cold plasma.

This present invention includes the ability to produce and control the rate the production of radiation including the ability to turn on and quickly reduce, by many orders of magnitude, the production of the a plasma. In addition to the production of ionizing particles, there is also experimental evidence that a low flux of neutrons may also be emitted from the active working electrode. However for applications requiring neutrons, it is possible to use the alpha or proton particles that are emitted from the working electrode to impact on a material such as Beryllium, which may also serve as the anode or the collector, to produce neutrons by means known in current art.

Many benefits of this invention result from the use of gases or vapors or mixtures of gases and vapors that include hydrogen. These benefits include the ability to operate at higher temperatures than those allowed for liquid electrolytes. Additionally, Linear Energy Transfer equations and plots show that high energy particles will travel much further in gases than in liquid which greatly expands the number of potential applications such as the production of a weakly ionized plasma. Gas pressures from a few torr to greater than ambient have been experimentally demonstrated and higher pressures could be beneficial for some applications. Non-particulate forms of radiation that are produced such as visible, UV, x-ray and gamma also have multiple uses.

BRIEF DESCRIPTION OF THE INVENTION

The inventive feature of this disclosure is that contrary to conventional art as described in the Background section of this disclosure, it is possible to produce one or more forms of radiation including visible, UV, x-ray and gamma, and particles including alphas, electrons, beta minus, beta plus, protons, tritons, and neutrons. Multiple applications exist for the various the forms of radiation produced including to ionize gases to produce a weakly ionized or cold plasma. Furthermore, these results are obtained while using materials that are not normally considered to be naturally radioactive and while using voltages, electric field strengths, and gas pressures that are outside the range required for Corona generation and/or Townsend discharge.

Critical components of this invention include one or more specially prepared and activated working electrodes that are typically the cathode, one or more counter electrodes that are typically the anode, and may include one or more collectors or targets to intercept the ionizing radiation, a power supply to provide voltage or current, a gas or vapor or mixtures of gases and vapors that includes hydrogen and a means to contain the gas between the electrodes.. The specially prepared working electrode must include a material that will adsorb, absorb, and occlude, store, or retain hydrogen within the lattice such as palladium or nickel and other elements and alloys such as the nickel-titanium alloy known as NiTiNOL. For some embodiments, palladium is deposited onto another metal such as copper or copper that has been plated with silver, gold or nickel. For other embodiments, the working electrode may be comprised of a foil, sheet, or screen of material that will form a hydride that may have been further deposited such as with palladium or nickel. The working electrode can also be comprised

of a screen that may not form a hydride that has been deposited with a material that will form a hydride. The counter electrodes are typically a metal conductor. For applications involving a collector or target, the collector or target material can be selected to take advantage of the ionizing radiation such as to produce electricity or to produce isotopes such as for medical applications. The ionizing radiation can also be used to ionize a gas or vapor including the possibility to alter the isotopic structure of the gas. At least one counter electrode serving as the anode and at least one working electrode serving as the cathode are positioned relative to each other and in fluidic contact with the gas or vapor mixture containing hydrogen between them. Other configurations of the electrodes depend upon the specific application. A voltage is supplied between the electrodes to produce the desired electric field between them.

Preparation and activation of the specially prepared working electrode is important. Multiple protocols have been successfully used and some examples of the protocols are described in different embodiments in the detailed description of the invention. To become active, the working electrode needs to have a sufficiently high loading of hydrogen or deuterium occluded within the metal lattice. In addition to gas pressure, it is possible to use electric fields of sufficient strength to produce fugacity, sometimes referred to as electrochemical charging, through a gas to help adsorb, absorb, occlude and retain hydrogen and isotopes in materials that will form a hydride such as palladium, nickel, magnesium, and numerous other elements and alloys of elements. Experiments have also shown that when the conditions are right, including electric field strength, gas pressure, and a sufficiently high ratio of hydrogen ions to metal atoms, the working electrode becomes 'active' and produces radiation that contributes to the ionization of the gas, resulting in an increased conduction between the electrodes that is several orders of

magnitude larger than current art predicts for similar conditions. In order to sustain its active state, it is necessary to maintain the ratio of hydrogen to metal in the working electrode. This is accomplished by maintaining the pressure and/or electric field through the hydrogen gas between the working electrodes and the counter electrodes. Hydrogen and its isotopes and ions will diffuse through metals such as palladium so it is important to construct the working electrode to include a non or low-hydrogen permeable barrier to prevent hydrogen from diffusing through the palladium or other materials that will form a metal hydride. By preventing the hydrogen from escaping in combination with the continued application of fugacity, high loading ratios of hydrogen to metal atoms in the lattice material can be maintained. For some applications where the use of a non or low-hydrogen permeable barrier is not used, fugacity is applied to both sides of the working electrode to contain the hydrogen.

Multiple device configurations of the anode and cathode are possible such as but not limited to parallel sheets, screens, concentric tubes, rods and wires and combinations thereof. Anodes have typically been tubes, rods, wires and screens selected from copper and brass but other conductive materials can also be used. In some medical applications using gas plasmas, one of the electrodes can be the human body. Multiple materials for the specially prepared and activated working electrode have been employed such as palladium and/or nickel as well as palladium and nickel that has been deposited onto another material such as silver plated copper electrodes and metal alloys such as NiTiNOL an alloy of nickel and titanium. Materials, alloys or combinations of materials that will hydride and/or into which hydrogen will diffuse are candidates to become active electrodes when properly prepared and activated. It is important that the working electrode be designed and configured such that the hydrogen is retained in the

lattice of the working electrode not allowed to diffuse through or out through edges or areas where gas pressure or fugacity is not as high. Multiple gases such as, for example, hydrogen, deuterium, and mixtures of gases that include hydrogen and deuterium, at pressures such as but not limited to -25" of Hg to +90 psig have been demonstrated to conduct a current between a electrically conductive anode and a specially prepared cathode. Separation distances from 1mm to greater than 10mm have been shown to successfully produce a plasma and conduct a current although other separation distances and pressures also should work. The test program of record has included both static and dynamic magnetic and electric fields and cell temperatures from a few degrees °C to well over 100 degrees Celsius with successful results.

The ability to produce a plasma indicates the presence of ionizing radiation being emitted from the specially prepared and activated working electrode. Ionizing radiation comes in several forms including ionized particles, gamma, X-ray, and UV. Past experiments using a liquid electrolyte have detected the production of high energy particles including alphas and/or protons and also the production of neutrons. Many applications take advantage of the radiation that is produced. Ionized particles will only travel a few millimeters in a liquid electrolyte but in a gas electrolyte even at atmospheric pressures, such particles can travel several centimeters or further. An ionization smoke detector is one example of current art where alpha particles with energy levels of approximately 5.4 MeV emitted by Am-241 will ionize air and travel approximately 5 cm before its energy is dissipated. The ionization smoke detector takes advantage of this to differentiate when smoke is mixed with the air which changes the ionization leading to a change in conductivity which the smoke detector uses to determine the presence of smoke. Another potential application is to use the impact of alpha particles onto materials such as Beryllium

which causes neutrons to be emitted. Neutrons have many applications such as to produce transmutations from one element to another and as the neutron source for a sub-critical nuclear reactor. Ionized particles produced by the method described in this patent can also be used to irradiate ferroelectric and alpha and/or beta voltaic devices to produce electricity or to produce a nuclear battery without the disadvantage of requiring significant amounts of materials that are naturally radioactive.

For some applications, it is desirable to ionize a gas that may not include hydrogen such as for medical applications where cold plasmas comprised of different gases are directed onto a treatment area. For this and other applications, the active working electrode can be placed between two counter electrodes. On one side of the working electrode, a gas containing hydrogen is between the working electrode and one counter electrode. On the other side of the working electrode, the gas that is between the working electrode and the second counter electrode to be ionized that may not include hydrogen. Hydrogen will be loaded into the working electrode from one side and prevented from diffusing out on the other side by the fugacity produced between the second counter electrode and the working electrode, thereby sustaining the ratio of hydrogen ions to metal atoms within the working electrode. The ability to modulate the electric fields impinging on one or both sides of the working electrode is an important advantage to optimize the output from the working electrode. To sustain the working electrode in its active state, care must be taken in the design, assembly, and operation of the cell to prevent the hydrogen from diffusing out of the working electrode lattice material. Several example embodiments that take advantage of the radiation produced by specially prepared

working electrode are described in the detailed description and other embodiments are envisioned.

BACKGROUND OF THE INVENTION

This disclosure describes a method and means to produce radiation from a specially prepared and 'activated' working electrode as demonstrated by the ability to conduct electrical current through a gas or mixtures of gases at gas pressures up to and above atmospheric pressures and at voltages that are significantly below those normally used in corona discharge or glow discharge tubes also known as Townsend discharge. In order to establish the novelty and utility, a comparison and analysis is presented to differentiate from current art.

Electrical conductivity σ or its inverse resistivity $\rho = 1/\sigma$ is defined as $\sigma = J/E$ where J is the magnitude of the current density and E is the magnitude of the electric field or electric field strength. For a uniform material, e.g., gas, liquid or solid, in the form of a parallelepiped of length ℓ metalized on the ends with cross sectional area A the conductance measured in siemens (S) is G [S] $= A/\rho\ell = i$[A]$/V$[V] where the current $i = J/A$ and $E = V/\ell$ where A is measured in [m^2] and ℓ is measured in [m], i is measured in amperes [A] and V is the voltage measured in volts [V]. Alternatively, G can be measured in [mS] and A and ℓ in [cm^2] and [cm] respectively.

A dry, 0 % relative humidity (RH), with the exception of radon (Rn), non-polar gases such as H_2, N_2, O_2 or the noble gases, e.g. He, Ne et al at engineering temperatures, pressures

and electric field strengths < 2000 K, P < 10,000 psi and E < 20,000 V) are considered to be an insulator although they are actually an extremely poor conductor. The conductivity of a gas increases with temperature but the conductivity of hydrogen (H_2) at P = 1 atm and T = 2000 K is $\sigma = 1.83 \times 10^{-14}$ mho/cm according to Jerrold M. Yos, "Transport properties of nitrogen, hydrogen, oxygen, and air to 30,000°K," RAD-TM-63-7, 22 March 1963.

Anomalous electrical conduction has been observed by InovL in gas filled cells using specially prepared and 'activated' electrodes and will be described in this patent application. The most easily analyzed embodiment of this invention is the InovL Cylindrical Gas-filled Capacitor (CGC) cell which is constructed from two coaxial conductive cylinders or electrodes sealed at each end where one of the seals is an electrical insulator to electrically isolate the inner conductor from the outer conductor as shown in Figure 1. Denote the radius of the inner conductor or electrode by a and the radius of the outer conductor by b. The space between the electrodes is filled with a gas and/or a vapor, typically deuterium (D_2) gas and/or heavy water (D_2O) vapor. The electrodes are connected to a high voltage (HV) power supply through a current limiting resistor, typically 1 MΩ to limit current flow and a an electrical potential V is established between the outer cylinder and the inner cylinder with the outer cylinder positive relative to the inner cylinder. Typical cell dimensions are a = 1/8" od with a length of ~ 9 cm and b = 28/32" id with a length of ~ 13 cm. The electrode separation is $d \approx 0.75$ cm and the volume of the cell is ~ 50 cm^3. Typical HV power supply voltages are 110 – 810 volts and typical operating pressures are 500 – 1500 torr or – 10" Hg gauge to + 15 psig. The physical geometry of this embodiment of the InovL CGC cell is similar to a cylindrical gas ionization chamber which is an accepted and current art method to detect external sources of radiation by

measuring a momentary change in conductivity of the gas in the chamber. For the InovL CGC cell, one innovation is that the potential on the two cylinders is reversed from that of the usual ionization chamber, the inner electrode is a specially prepared and 'activated' metal hydride, and in the InovL cell the conduction is typically continuous not momentary.

Electrical conduction in a gas or a vapor has been extensively studied and depends on several quantifiable variables as well as the type or composition of gas or vapor and the geometry and type of electrodes used to apply a voltage across the gas or vapor. The three primary variables that determine the conduction of electricity in a gas or vapor are the electric field strength, E, the number of ions/(cm^3 or cc), N_{cc} and the mobility of the ions, μ. Three secondary variables or parameters also determine the conduction of electricity in the gas or vapor. These parameters are the relative humidity (RH) specified as a percentage or the saturation, s, of the water vapor where s = 1 corresponds to a RH = 100 %, the temperature of the gas or vapor, T, measured in kelvin but usually specified in degrees Celsius and the pressure, P, typically specified in torr (~ 1 mmHg) where 760 torr = 1 atm ≈ 30 "Hg ≈ 15 psia. For specified values of T, P and s the tree primary variables are related in the following manner: $J = N_{cc}\,\mu\,E$ where J is the current density. By examining these six variables for the already known electrical conduction phenomenon for gases and vapors the novelty of the InovL observed anomalous electrical conduction can be established.

One of the most important contributions to an understanding of the physics of the conduction of electricity in gases was the work of J.J. Thompson. In 1906, the same year he was awarded the Nobel Prize in Physics for his work on the Conduction of Electricity Through

Gases, J.J. Thompson published the second edition of his book titled *Conduction of Electricity Through Gases,* 2nd Ed. 1906, where he wrote:

"I have endeavored in this work to develop the view that the conduction of electricity through gases is due to the presence in the gas of small particles charged with electricity, called ions, which under the influence of electric forces move from one part of the gas to another".

By 1906 others had already begun to apply the knowledge that the conduction of electricity through gases was due to the presence of ions in the gas to the practical problem of measuring this conduction in air. In 1905 H. Gerdien, published in German, "Demonstration eines apparatus zur absoluten messung der elektrischen leitfahigkeit der luft," *Physikalische Zeitschrift,* 6, 800-801, in which he described the construction of an instrument that is now known as the Gerdien condenser. As commonly implemented, the Gerdien condenser is a coaxial arrangement of two conducting cylinders open at both ends so that the experimental gas, usually air, can be forced through the space between the two cylinders. An electrical potential is applied between the cylinders and the resulting current is measured. Depending on the sign of the applied voltage the conductivity of either positive ions or negative ions can be measured. The construction and operation of a modern Gerdien condenser is described in Karen Louise Aplin, *Instrumentation for Atmospheric Ion Measurements,* PhD Thesis, The University of Reading, August 2000. The primary difference between the Gerdien condenser and the example CGC embodiment described in this patent application is the incorporation of a specially prepared and 'activated' working electrode, typically the cathode.

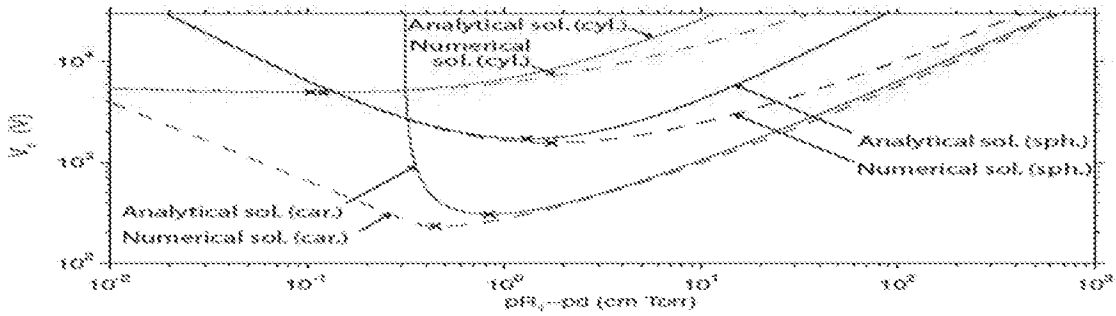
In 1910 John S. Townsend F.R.S. in his book, *The Theory of Ionization of Gases by Collision*, wrote:

"After studying the changes which take place in the conductivity of gases through which ions are passing under various conditions, I was led to propose the theory of ionization by collision to explain the development of currents in gases. The accuracy of the theory has been established by a large number of experiments specially arranged to measure conductivities which could be compared with the values obtained from theoretical considerations". Townsend envisioned that electrons in a gas at low pressure, where the mean free path for electron-atom collisions was long, experience a force on them due to the electric field that accelerates them until they acquired enough energy (~ 36.5 eV for D_2 gas) to form additional electron-ion pairs thus ionizing the gas. This 'Townsend discharge' process the basis of neon and florescent and other glow discharge tubes, cannot explain the anomalous conduction of the InovL CGC cell since the InovL CGC cell's conduction is six or more orders of magnitude greater than that of an InovL CGC cell without a specially prepared and 'activated' electrode. In addition, the InovL CGC cell operates at near atmospheric gas pressure, where the mean free path is too small to allow the electrons of a 'Townsend discharge' to accelerate to the gas ionization energy.

Townsend in his work cited above also reported on the freeing of electrons from the negative metal plate of a cell and their subsequent acceleration by the electric field, when it was illuminated with ultraviolet light, due to the photoelectric effect described by Einstein in 1905 for which, in part, he won the Nobel Prize in Physics in 1921. Townsend also reported on the conductivity of gas illuminated by electromagnet radiation of a wavelength known as Röntgen

rays (x-rays). However, the InovL cell is opaque to visible and ultraviolet radiation and significantly attenuates x-ray with energy below 100 keV so that neither of these external electromagnetic radiation sources can cause the observed anomalous conduction.

Consider collisions caused by electrons accelerated by an electric field as described by Townsend. It is known that the energy required by a high velocity electron to ionize a hydrogen atom in a hydrogen molecule is given by the W-value of ~ 36.5 eV for H_2 gas where W-value is the mean energy expended in a gas per ion pair formed. Ref: ICRU Report 31, "Average Energy Required to Produce an Ion Pair", 1993. This means that the electric field strength of an electron in hydrogen gas at the specified temperature and pressure must be greater than 36.5 volts per mean free path. This is typically achieved by having a gas pressure-distance product that satisfies the Pashen curve for a specific cell geometry. Ref: A. S. Gibson, J. A. Riousset, and Victor P. Pasko, "Minimum breakdown voltages for corona discharge in cylindrical and spherical geometries," *riousset.com/jeremy/wp-content/uploads/Gibson2009 1.pdf*.



(a) Comparison of the breakdown voltages with respect to pd or pR_1. The dashed lines show the numerical solutions, while solid lines show the analytical solutions. The (car.), (cyl.), and (sph.) additions correspond to the Cartesian, cylindrical, and spherical solutions respectively.

From the curves for the cylindrical geometry case in the above figure the minimum voltage required is ~ 5000 V which is outside the operating conditions for the InovL cell. Thus

high velocity electron collisions from electrons incidentally formed inside the cell cannot be the source of the anomalous conduction.

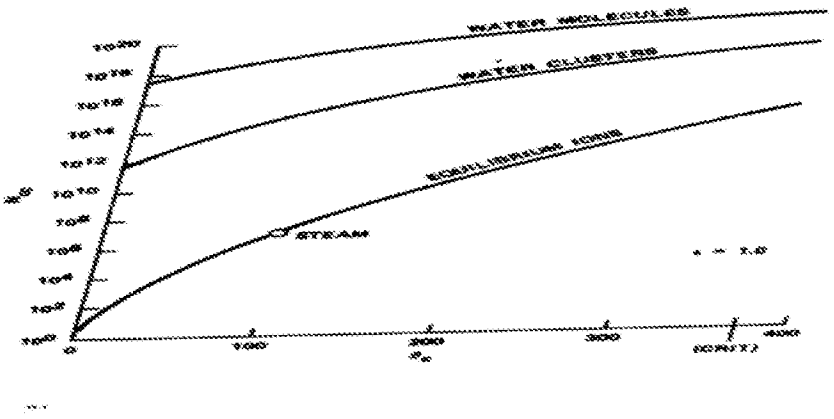
In 1920 F.W. Peek, Jr. published the second edition of his book titled *Dielectric Phenomena and High Voltage Engineering*. In this book he describes in detail the process of corona discharge generation in a gas at or near atmospheric pressure and normal room temperature of 25 °C. In particular, he discusses the conditions necessary for the onset of corona discharge in air filled coaxial cylinders as a function of the diameter of the inner conductor and the electric field between the inner and outer conductor. Peek shows that the onset of visible corona in the gas occurs when the electric field gradient at the surface of the inner electrode reaches a critical value that depends on the gas, the relative humidity (RH) of the gas, the roughness of the electrode and the radius of the electrode but not directly on the diameter of the outer electrode but instead on the natural logarithm of the ratio of the radius of the inside of the outer electrode, R, to the radius of the outside of the inner electrode, r, provided that $\ln(R/r) < 2.718$ (Euler's number). Peek showed that the critical electric field or gradient is less for a wet (RH ~ 100%) electrode than for a dry electrode and that a rough or irregular electrode also decreases the value of the critical electric field. Corona discharge will initiate at the surface of the inner electrode when the electric field at the surface of the inner electrode is exceeds the critical electric field. Using deuterium (D_2) as the gas, RH = 100 % and a roughness factor of 0.77 the critical field is calculated to be ~11.3 kV/cm while for the same condition with air as the gas the critical field is ~22.0 kV/cm as measured by Peek and reported in his book. However, the actual electric field for the highest voltage across the cell results in an electric field at the InovL CGC inner electrode of only ~2.052 kV/cm out of a needed ~11.3 kV/cm for visible

corona discharge initiation. Thus corona discharge cannot explain the observed anomalous electrical conduction.

In 1920 an alternative method of ionizing gases was reported by Megh Nad Saha, "LIII. Ionization in the Solar Chromosphere," *Philosophical Magazine. Series 6. 40 (238): 472, Saha* showed that thermal collision of the atoms, i.e., the molecular motion of a heated gas, also would ionize some of the atoms in the gas thus making an ionized gas. The number, N_{cc}, of ionized hydrogen atoms/cc Saha showed can be computed from the equation he developed. However, at temperatures less than 2000 K the equation does not predict enough ions to explain the observed InovL CGC cell anomalous conduction. Ref: "3. Plasma ionization. Saha equation. – Stanford Solar Physics," available on the web at sun.stanford.edu/~sasha/PHYS780/PLASMA_PHYSICS/phys780_2014_13.pdf .

External particulate radiation by natural radiation (alpha, beta or protons) from radioactive elements in the earth or in the atmosphere surrounding the cell cannot penetrate the InovL cell and thus cannot be the source of the observed conduction. Atmosphere muons generated by cosmic rays entering the earth's atmosphere have sufficient penetrating power to pass through the outer cylinder of the InovL cell and ionize the gas inside. However, the muon flux at the surface of the earth is only about 1 muon /cm^2 per minute. Ref: Atmospheric Muons – HyperPhysics Concepts, *hyperphysics.phy-astr.gsu.edu/hbase/Particles/muonatm.html* . *This ionization density is much to small to account for the conduction observed in the InovL CGC cell.*

Another possible explanation based on current art for the InovL CGC cell's anomalous conduction is the presence of a polar gas or vapor, e.g. water (H_2O) or heavy water (D_2O) vapor or steam. This vapor has a varying number of naturally occurring ions depending on its temperature and thus both the temperature and the saturation, *s*, or relative humidity (RH) are important parameters. Hugh R Carlon, "Electrical properties of atmospheric moist air: a systemic experimental study," CRDEC-TR-88059, September 1988, shows that the number of ions/cc is a strong monotonic function of the RH of the moist air. However, for a temperature of 25 °C even at a saturation of s = 1 or RH of 100 % the ion density is less than 3 x 10^5 ions/cc and thus cannot be the source of the observed InovL cell conduction. Hugh R. Carlon, "Electrical Conductivity and Infrared Radiometry of Steam," ARCSL-SP-80006, April 1980 presents data on the ion density of saturated (s = 1) water vapor as a function of Celsius temperature up to the triple point of water, i.e., ~ 375 °C. This data is presented in Figure 6 of Carlon's report and is reproduced below.



"Figure 6, Number of Water Monomers, Clusters ("c" =10) and Equilibrium Ions in Saturated Air or Vapor ("s" = 1.0) vs. Celsius Temperature."

An examination of Carlon's Figure 6 shows that at a temperature of 200 °C and s = 1.0 the density of ions due to water clusters is N_{cc} = ~ 1 x 10^{11} ions/cc and confirms the known fact that steam is a conducting vapor. However, even this ion density is about 9 orders of magnitude less than the number of un-ionized water molecules and at room temperatures, the difference is several orders of magnitude more. Thus, conduction in water vapor cannot account for the observed InovL CGC cell's anomalous conduction.

In terms of the number of positive ions, n^+ collected at the negative potential inner electrode or cathode, the cell current can be written as $i \approx \sigma CV/\varepsilon_0 = n^+ q\mu VC/\varepsilon_0$ where $q \approx 1.602$ x 10^{-19} coulombs (C) is the charge of the electron, n^+ is the number of positive ions and μ is the mobility of the ions. From this representation of the cell current it can be seen that cell current or cell conductivity is proportional to the number of positive ions in the gas. Now by examining each of the possible gas ionization mechanisms one after the other it will be seen that the anomalous InovL CGC cell current or conductance cannot be explained by any mechanism or combination of known mechanisms other than by some form of radiation from a specially prepared and activated 'active' cathode.

Based on the discussion above it is postulated that the only explanation for the InovL CGC cell's anomalous conduction is that ionizing radiation, including at least one of multiple forms of radiation such as photons including visible, UV, x-ray and gamma, and particles including alphas, electrons, beta minus, beta plus, protons, and tritons, is originating within the cell due to the 'activation' of the cell's PdD deuteride cathode. As shown, none of the above prior art methods can explain the anomalous conduction of gases and vapors observed by InovL

researchers in cells, with specially fabricated and activated cathodes, operating at temperatures near and above room temperature (289 K or 25 °C) and pressures near and above atmospheric pressure e.g. 500 to 1500 torr, where 760 mmHg (torr) or 1 bar = 100,000 Pa (~ 30 "Hg) represents atmospheric pressure. Prior art, US Patent 8,419,919 titled "SYSTEM AND METHOD FOR GENERATIONG PARTICLES," teaches that properly prepared electrochemical cells utilizing a liquid electrolyte will produce multiple forms of ionizing radiation. The inventive feature of this present disclosure is that contrary to conventional art, it is possible to produce ionizing radiation in a gas or vapor when a properly prepared and 'activated' working electrode is used, thereby greatly increasing the utility of the phenomenon as shown in multiple example embodiments.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 is a drawing of one example embodiment of a cell that is configured similar to a Cylindrical Gas Cell radiation detector with the distinction that the radiation is produced inside the cell by the working electrode.

Figure 2 is a plot from experimental data to show the cell conduction before and after the working electrode is 'activated.' After activation, significant current is conducted at voltages that are well below those required for Corona breakdown or Townsend discharge voltages.

Figure 3 is a plot of data taken from the same cell at two different gas pressures showing an increase in current at higher pressures which is counter to current art.

Figure 4 is an embodiment of a cell design that will produce ionizing radiation to ionize gases for a variety of applications.

Figure 5 is a modification to embodiment of that uses the ionization described in Figure 4with the application of a magnetic or electric field to produce thrust via Electro or Magneto Hydrodynamic effects.

Figure 6 illustrates an embodiment that uses the kinetic energy from the high energy particles being emitted to produce energy for a variety of applications.

Figure 7 illustrates an electrical schematic or a three-electrode configuration including a working electrode, a positive grid counter electrode, and a collector electrode with a "load" resistor as one means to harvest energy.

Figure 8 is data from the three-electrode test of Figure 7 showing the collection of current at the collector electrode to ground through a load resistor.

DETAILED DESCRIPTION OF THE INVENTION

Multiple embodiments are described to illustrate the wide variety of applications that are possible utilizing the capability to produce ionizing radiation as described in this patent. Multiple materials, cell designs, physical configurations, and preparation techniques have experimentally been shown to successfully produce radiation to ionize the gas and conduct significantly more current when using a prepared cathode that has been activated than when using unprepared cathodes. Several methods and protocols have been used successfully. Figure 1 illustrates one embodiment **100**. One method to prepare the cathode begins with a ¼" diameter copper tube approximately 4 inches long **4** that is cleaned with a saltwater and acetic acid solution, a plastic cap is placed on the copper tube to prevent the plating bath from getting inside the tube and then the copper tube is placed in a silver plating bath. The silver plating solution is a commercially available product, for example the Krohn "Ready-To-Use Silver Electroplating Solution". For silver plating, the Cu tube is the cathode and a silver wire is the anode. Approximately 3.3 volts is applied for one minute resulting in a variable amperage over the plating time. The silver plated cathode is then allowed to dry.

A palladium overcoat **5** is then electrodeposited in the following manner: The silver plated copper tube is the cathode in an electroplating bath comprising aqueous 0.15 molar LiCl solution and enough aqueous 0.03 molar $PdCl_2$ solution is added to form a palladium layer about 1500 atoms thick on the surface to be plated. The plating bath and cathode are cooled to less than 4 °C. The anode for the palladium plating is platinum wire. The plating is started using a current density of approximately 0.016 amperes per square centimeter of surface area. The

surface area is typically about six square centimeters and typically about 6 volts and 0.10 amps are applied for 15 minutes. After 15 minutes the current is increase to approximately 0.167 amperes per square centimeter, typically requiring about 22 volts and 1.0 ampere for 45 minutes. After the 45 minutes period an additional amount of aqueous $PdCl_2$ solution is added to form another palladium layer about 1500 atoms thick on the surface to be plated. After a further hour at approximately 0.167 ampere per square centimeter current in the electroplating bath, the plated electrode is removed from the electroplating bath and allowed to dry for approximately 18 hours. After the rest period, the plating procedure from above was repeated to put another coat of palladium on the electrode. Multiple platings can be performed to provide the desired palladium thickness to form the cathode **4**. Alternative plating protocols such as using normal room temperature plating bath, different voltages, currents, and time and substituting D_2O for the H_2O aqueous plating solution have also successfully produced an "active" working electrode.

After the cathode preparation is complete, the cap on the end of the cathode **4** is removed and the cathode is attached to manifold **10** which is composed of brass valves **13**, and **14**, and pressure gauge **15** connected via standard brass fittings **17**. The manifold is attached via the brass nipple **7** to the brass fitting **6** and through the nylon or Teflon insulating bushing **8**. A calculated amount of Li foil, **19,** typically about 0.126 grams for the experimental cell described above, is placed in the bottom of the end cap **2** and the cell is assembled by screwing end cap **2** and the brass bushing **9** onto the brass ¾ inch diameter by 4.5 inch long nipple **1** which is also the anode for this embodiment. The insulating bushing **8** along with the previously attached manifold **10** are screwed into the brass bushing **9**. Care is taken to be sure that all fittings are gas tight.

The cell is connected to a regulated DC power supply capable of supplying up to 1000 volts and 6 mA using the anode electrical connection **3** and the cathode electrical connection **16**. The cell is also connected to a computerized, 14 channel LabJack instrumentation recording system typically set to record 500 samples per second using the anode electrical connection **3** and the cathode electrical connection **16**. A vacuum pump is attached, for example to the open end of valve **14** and valves **13** and **14** are opened. A vacuum is pulled until the compound pressure gauge **15** measures approximately -26" to -28" Hg. Valve **13** is now closed and the vacuum lines removed from valve **14.** A predetermined amount of D_2O, typically 1 ml can be inserted between valve **13** and **14**. Valve **14** is then closed and valve **13** is opened, allowing the D_2O to drop down through the cathode **4** onto the Li foil **19**. It is important to allow sufficient separation between the bottom of the cathode **4** and the anode **2** so that a short will not occur between the anode and the cathode as the Li foil **19** reacts when D_2O is added to the cell. The Li foil should have sufficient number of moles so that when it is reacted with an excess amount of D_2O the resultant D_2 gas **18** will have the desired pressure, typically 15 to 30 psig for the volume of the cell **100**. The DC power supply is turned on to provide a voltage across the cell through a current limiting resistor, typically 1 MΩ because of the maximum current limitation of the power supply. For this geometry, the voltages are typically approximately 650 volts although a range of voltages has been successfully used. Activation of the working electrode involves loading deuterium into the working electrode to form a metal deuteride. Two mechanisms contribute to this process. One is by the gas pressure in the cell and the other is by fugacity, also called electrochemical charging where the D_2 gas is adsorbed and deuterium is absorbed by diffusion and stored or occluded in the working electrode lattice material.. Although the initial conduction

in the cell will be low because it results primarily from the conductivity of the D_2O vapor in the deuterium gas, fugacity is occurring to assist the loading of deuterium into the working electrode lattice material. As more deuterium is being adsorbed, absorbed and stored or occluded in the working electrode in the form of a metal deuteride, the working electrode will become 'active' and the conduction will increase by several orders of magnitude and the voltage across the cell will be reduced as more current is passed through the current limiting resistor. At this point, the working electrode is "activated" and producing ionizing radiation which is actively contributing to the ionization of the gas resulting in increased current being conducted by the reduced voltage across the cell. Figure 2 is a plot of the first 2500 files representing approximately 43 hours of data from a test using this embodiment. Initial voltage was 900 volts between the anode and the working electrode and after approximately 38 minutes, the working electrode became active. The voltage across the cell dropped to approximately 60 volts and remained there for approximately 30 hours during which time the current was approximately 765 uA. The ability to conduct 765 uA of current is several orders of magnitude greater than current art predicts for the electric field produced by 60 volts. After approximately 30 hours, conduction gradually decreased and the cell voltage increased. It is also possible to activate the electrode by creating low gas pressures in combination with high electric field strengths that will create a Corona or Townsend discharge to load the gas into the working electrode material at which time the electric field reduced and the gas pressure can be increased to ambient pressure or above which may be required for sustained operation by some applications. When the working electrode is active, the current between the working electrode and the anode is several orders of magnitude greater than conventional art predicts for the electric field strength between the anode and the cathode. Figure 3 illustrates the conduction of a fully activated cell as a function of voltage for cell gas at

two different pressures. The cell had been conducting current for several months and over that time, the gas pressure in the cell had dropped to -7.5 "Hg. A test was conducted by reducing the voltage between the electrodes and recording the change in conduction. After the test, additional deuterium gas was added to the cell bringing the pressure up to 11 psig. After the cell had stabilized to the new pressure, the voltage was again reduced and the cell conduction was recorded while the cell was at the higher pressure. As can be seen in the plots, when the cell was at higher pressure, it conducted significantly more current than the same cell at lower gas pressure for the same voltages. This can be explained in part that at higher pressure there are more gas atoms to ionize by the ionizing radiation being emitted by the activated working electrode. .This illustrates how gas pressure can be adjusted for some applications to optimize the use of the ionizing radiation.

For some applications, it is desirable to produce a plasma in a gas or mixture of gases and vapors that may not contain hydrogen. Figure 4 illustrates an embodiment design **400** that will produce ionizing radiation to ionize a gas or mixtures of gases that may or may not contain hydrogen at ambient pressures and temperatures where the ions can be directed onto a target such as for a medical application. For this embodiment, the working electrode **401** is prepared by using one of several protocols such as depositing Pd from a solution of LiCl onto both sides of a foil or screen that will adsorb, absorb, and occlude hydrogen within the lattice. Examples include Pd or NiTiNOL foil or a screen material such as but not limited to Ni screen. The deposited Pd must be thick enough to fill in the openings in the screen material to form a barrier that will prevent gases other than hydrogen or deuterium gas from passing through. Since hydrogen will diffuse through Pd, as shown in Figure 4, the working electrode is positioned

between two positively charged counter electrodes. A gas or mixtures gases or vapors that include hydrogen **403** are contained in the volume between the working electrode **401** and one counter electrode **402** which is comprised of a combination of solid and grid conductors at a positive potential, with the electrodes being separated by a non-conducting and non-hydrogen permeable materials **408**. Ports for gas and feed-throughs for electrical signals **410** are installed as necessary. The voltage on the counter electrode **402** and the working electrode **401** may be set to use fugacity to assist adsorption and absorption of the hydrogen or deuterium gas into the working electrode. A voltage is supplied to the second counter electrode **404** to provide an electric field between counter electrode **404** and the working electrode **401** and the voltage is adjusted to provide an electric field strength that produces fugacity that is opposite to fugacity that is produced by the electric field between counter electrode **402** and the working electrode **401** to prevent the hydrogen from passing through the working electrode material and retain the ratio of hydrogen ions to metal atoms within the working electrode material. In order to prevent hydrogen from diffusing out the edges of the working electrode, a low permeable barrier may be used. This can be accomplished by plating a low hydrogen permeable material such as Copper, Gold, or Silver around the edges of the working electrode and/or may also use a thin coating of a non-conducting epoxy such as J-B Weld Epoxy Adhesive or non-conducting high-temperature ceramic material such VersaChem Exhaust Repair Muffler Weld. Make sure to provide an electrical connection to the working electrode material during this process. After the working electrode has been assembled, if desired Pd or Ni or other materials may be deposited on both sides of the working electrode via one of several means such as electrochemical, sputtering, or vapor deposition. Multiple electrochemical plating baths and plating protocols have been used

(References). The plating should be thick enough so that hydrogen gas will not pass through the working electrode material except by diffusion.

After the working electrode has been plated with palladium the cell can be assembled as shown in Figure 4 with the volume between the working electrode **401** and the counter electrode **402** being a sealed container. The epoxies used around the edges of the working electrode may be used to assemble and seal the cell. After the cell is assembled, the volume between **401** and **402** is evacuated and refilled with hydrogen or deuterium gas **403** and the valve **411** is closed to prevent leakage. Voltages are then applied between the counter electrodes **402** and **404**, typically the anodes and the working electrode **401** which is typically the cathode to produce fugacity to help adsorb and absorb hydrogen or deuterium into the working electrode material from one side and prevent it from diffusing out the other side.

When the working electrode becomes active, ionizing radiation will be produced from both sides of the working electrode. Ions that are produced between the working electrode **401** and anode **402** will ionize the hydrogen gas **403** with the positive hydrogen or deuterium ions beings loaded into the active working electrode to sustain the activity. Ionizing radiation emitted from the working electrode **401** toward counter electrode **410** will pass through the grid counter electrode **404** and will ionize the mixture(s) of gases and produce a cold plasma in the volume between the counter electrodes **404** and **410**. It should be recognized that this configuration could also include concentric cylinders with anode **402** being the centerline. It should also be recognized that by applying modulated electric fields between the counter electrodes **402** and **404** and the working electrode **401**, the fugacity pressure can alter the mobility of the hydrogen

or deuterium ions that are occluded in the lattice of the working electrode to allow optimization of the ionizing radiation being emitted. Other configurations with similar functionality are also envisioned.

Plasma's of mixtures of gases have multiple applications. Examples include treatments for a variety of medical conditions such as treatment of tooth decay and improved healing of burns.(REFERENCES saved in references folder). For these applications, the gas or mixture of gases **405** to be ionized is injected into the ionization chamber **406** and out through an opening **407**. Another example is to reduce the energy required to ionize the gas for an ion thruster that is used in space craft applications. Multiple applications are also envisioned to capture and transfer the momentum of the ionizing radiation to generate mechanical, thermal, or electrical energy.

Figure 5 illustrates a modification to the embodiment of Figure 4 with the addition of an electric and/or a magnetic field **508** that is properly aligned to direct and assist in acceleration of the ionized particles thereby producing an electro or magneto hydrodynamic thrust. The ability to use lower energies to ionize gas provides a significant advantage over conventional methods to ionize a gas for magneto and electro hydrodynamic applications.

Figure 6 illustrates an embodiment to use of the kinetic energy from particle emissions to produce thrust. The ability to produce and control the flux of high energy particles over a long period of time can produce thrust for multiple applications. It is estimated that for each Curie of 10 MeV alpha particles emitted, approximately 0.02237 kgf·m of work is produced which is

equal to 0.041 ft-lbs of work. Thus, if alpha flux is one Curie per square cm, a device of approximately one square foot of area would produce particles totaling approximately 38 ft-lbs of work. Since the particles are emitted over a 180 degree spherical direction, the net thrust perpendicular to the working electrode is 1/2 of the total momentum or approximately 19 ft-lbs of work per second. This configuration is similar to Figure 4 with the exception that the electric field supplied from anode **609** to prevent hydrogen or deuterium from diffusing through the working electrode is a grid or screen through which the high energy particles **610** will pass. The energy imparted to the energetic particles **610** will produce an equal but opposite thrust **611**. The separation distance between anode **609** and the working electrode **401** can be adjusted to maximize the thrust while minimizing the amount of current that the grid collects from any ions produced by the high energy alpha particle. Multiple configurations and applications are envisioned including thrust for vehicles, thrusters on the tips of propellers or a rotating turbine or machinery, fixed thrusters directed toward a rotating turbine blade and combinations thereof.

Figure 7 illustrates an example embodiment of a three electrode functional configuration schematic **700** including a vessel **701** filled with a gas or vapor containing hydrogen **702,** a specially prepared and activated working electrode **703** cathode and optional heater **707**, an anode comprised of a grid or screen or multiple element ion optics **704**, a variable voltage power supply **706** and one or more collectors comprised of one or more conductors, semi-conductors, or ferroelectric materials **705**. Ionizing particles produced by the activated working electrode will ionize the gas in the vessel. The positive ions produced between the working electrode and the anode will return to the working electrode to be adsorbed and absorbed by the working electrode to sustain the activity while other positive ions and positive

radiation will be collected at the one or more collectors. In both cases, the electrons will move to the anode. The collectors can comprise materials such as a piezo or pyro electric material to produce electrical charge or alpha-voltaic or a beta voltaic devices to produce electrons that can be harvested.

Figure 8 is test data from a three electrode configuration described in Figure 7. Channel v10 is the current conducted between the working electrode **703** and the grid **704**. Channel v8 shows the conduction between the collector **705** and the grid **704**. The voltage applied between the electrodes was well below breakdown voltage. The data indicates that high energy particles were getting through the grid to provide conduction which results negative current because of the cathode "load" resistor in the circuit. (Z512L18v15 dataset)

CLAIMS

Claim 1. The gas-phase ionizing radiation generator comprising a container with ports and electrical feed-throughs, one or more specially prepared working electrodes that includes a hydridable material, one or more counter electrodes, a voltage or current source connected to the electrodes, counter electrodes separated and electrically insulated from the working electrodes in the absence of any gas or vapor, and a gas or vapor or mixtures thereof containing hydrogen or its isotopes where the gas is in contact with the electrodes and wherein the ionizing radiation produced can be controlled by a combination of cell parameters such as voltage between the electrodes, magnetic fields, temperature, and gas pressure, mixture and relative humidity.

Claim 2. The gas-phase ionizing radiation generator of claim 1 wherein the ports and electrical feed-throughs in the container can be sealed to retain the gas or vapor or mixtures thereof.

Claim 3. The gas-phase ionizing radiation generator of claim 1 wherein the specially prepared working electrodes are activated by loading hydrogen or deuterium gas into the lattice of the hydridable material to form a metal hydride or deuteride.

Claim 4. The gas-phase ionizing radiation generator of claim 3 wherein the activation process includes the use of gas pressure and/or the application of a voltage or current source to produce fugacity or electrochemical charging to cause the hydrogen to be adsorbed, absorbed, and occluded or stored in the hydride material.

Claim 5. The gas-phase ionizing radiation generator of claim 3 wherein the specially prepared working electrode may include a means to prevent the hydrogen from leaking or diffusing out of the hydride material such as a non or low permeable hydrogen barrier and or an opposing fugacity.

Claim 6. The gas-phase ionizing radiation generator of claim 1 wherein the radiation includes one or more forms of radiation such as photons including visible, UV, x-ray and gamma, and particles including alphas, electrons, beta minus, beta plus, protons, tritons, and neutrons.

Claim 7. The gas-phase ionizing radiation generator of claim 1 wherein one or more of the counter electrodes can be comprised in part of beryllium or another material that will produce neutrons when bombarded with proton or alpha particles.

Claim 8. The gas-phase ionizing radiation generator comprising a container with ports and electrical feed-throughs, one or more specially prepared working electrodes or cathodes that includes a hydridable material, one or more counter electrodes or anodes that are comprised of a screen or grid capable of providing fugacity at the working electrode while allowing the ionizing radiation to pass through, an additional structure to intercept the momentum of the ionizing radiation and thus can convert its energy for useful applications, a voltage or current source connected to the electrodes, counter electrodes separated and electrically insulated from the working electrodes in the absence of any gas or vapor, and a gas or vapor or mixtures thereof containing hydrogen or its isotopes where the gas is in contact with the electrodes and wherein the ionizing radiation produced can be controlled by a combination of cell parameters such as

voltage between the electrodes, magnetic fields, temperature, and gas pressure, mixture and relative humidity.

Claim 9. The gas-phase ionizing radiation generator of claim 1 wherein the specially prepared and activated working electrode is configured so that the hydrogen is adsorbed, absorbed, and loaded into the lattice material from one side and prevented from diffusing out the other side by the application of fugacity produced by applying a voltage or current to a counter electrode on that side of the working electrode.

Claim 10. The gas-phase ionizing radiation generator of claim 9 where radiation is emitted from both sides of the specially prepared and activated working electrode.

Claim 11. The gas-phase ionizing radiation generator of claim 10 wherein the gas that is ionized on one side of the working electrode may not contain hydrogen.

Claim 12. The gas-phase ionizing radiation generator of claim 9 where the radiation produced at the specially prepared working electrode includes particles.

Claim 13. The gas-phase ionizing radiation generator of claim 1 wherein the radiation produced can be used in concert with a voltaic device such as an alphavoltaic, betavoltaic, or photovoltaic to generate electricity.

Claim 14. The gas-phase ionizing radiation generator of claim 12 wherein the kinetic energy in the particles can be harvested for applications such as to produce work or other mechanical motion.

Claim 15. The gas-phase ionizing radiation generator of claim 1 wherein the radiation produced can be controlled by changing cell parameters such as gas pressure, gas mixture, temperature, magnetic field and voltage applied between the counter and working electrodes.