Stimulation of LENR-AHE by high power electric pulses on coiled coaxial Constantan wires at high voltage and temperature

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Stimulation of LENR-AHE by high power electric pulses on coiled coaxial Constantan wires at high voltage and temperature[1]

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Introduction

This short presentation introduces an experimental design for the enhancement of the anomalous thermal phenomena (AHE) observed since 2011 in Constantan[3] wires exposed to a deuterium or hydrogen atmosphere, and heated by direct current. In fact, the occurrence of AHE requires specific conditions such as deuterium/protium absorption in the wire, sufficiently high temperature, as well as presence of strong non-equilibrium conditions such as those induced by thermal gradients, variations of pressure, and electric/magnetic fields. Previous experiments provided a strong evidence for the role of a flux of active species through the wire or at the wire surface. Though various techniques to induce a flux were tested before, and have been instrumental for a phenomenological understanding of AHE occurrence, they could not provide a solution for a sustained and exploitable energy production. For instance, wires loaded with deuterium at 700 C and 1 Bar, may show the occurrence of AHE when the pressure is slowly reduced to 1 mBar. During this process, an increase of wires electric resistance is observed and corresponds to the out-gasing of deuterium or hydrogen; this creates a flux associated with AHE. Nonetheless when the out-gasing ceases, the phenomenon tends to vanish. Similarly, simple knots along the wires, can be used to create hot-spots and corresponding thermal gradients; this approach proved quite effective and AHE could exceed 40% with respect to the electric input to heat the wires [1]. Notwithstanding, the method was affected by a cumbersome preparation of the wires and their frequent breaks. In 2016 a second non heated wire was positioned near the active hot Constantan and, at a sufficiently reduced pressure did reveal a thermionic emission of electrons from Constantan. The empiric correlation between this electron emission and AHE occurrence was initially puzzling, but soon lead to experiments where the electron emission was enhanced by mean of an external power supply to sustain an active voltage bias among Constantan and the second wire (anode). This approach also proved able to trigger AHE though not indefinitely. The next step was using an alternating current between the two wires, an approach which led to observe the occurrence of Paschen or dielectric barrier discharges (DBD) when voltage and pressure were in the appropriate range. Interestingly in presence of these discharges, we recorded high and long lasting AHE as observed by other authors before [2] [3] [4] [5] [6]. An intense scrutiny of the data collected from the experiments mentioned above led us to design an updated setup which could take into account the learning of almost ten years of Constantan wires studies. This setup includes the implementation of pulsed power supply based on a previous concept used by some of the authors of this presentation in electrolytic experiments with palladium [7] [8]. This power supply configuration and overall circuitry, is capable of providing powerful negative pulses along the wire, and positive pulses among the wire and an iron tube anode on which the wire (insulated with a special glass fiber sheath) is coiled. The positive pulses among the Constantan and the tube are used in particular to trigger Paschen or DBD discharges, while the tube can also be used as support for a multilayer coating of nickel-copper and low work-function oxides described in previous works [9].

[1] This presentation is a very preliminary overview of the setup that is being developed for upcoming experiments.
[2] All the Authors have been proponents of the participation to CleanHME, an European project of Horizon 2020 framework.
[3] $Cu_{55}Ni_{44}Mn_1$

OUTLINE

- **INFN-LNF pioneering the use of high power electric pulses in electrolytic environment.**
- **Constantan, as a cost effective alternative and a more robust solution to palladium.**
- **The reactor core and the coaxial coiled wire geometry.**
- **The iron core as a counter-electrode and enabler of various operating regimes.**
- **The general scheme of the new "dual" pulsed power supply and circuitry.**
- **Some speculations on Constantan wires coated with Low Working Function materials in presence of dielectric barrier discharges.**
- **Some similitudes among the current experimental setup and the Otto Cycle of internal combustion engines.**
- **Conclusions.**

Introduction

- **INFN-LNF (Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Frascati) has been continuously engaged in Cold Fusion-LENR studies since March 1989.**
- **Some of the authors of this report, where among those initiating this line of research at INFN.**
- **In 1994 electric pulsed were used in low temperature[4] experiments on plates[5] and wires made of Palladium and its alloys.**
- **The use of pulses aimed at enhancing the effects of Electromigration of deuterium or protium.**
- **The whole program of the time considered the occurrence of "coherence" as per G. Preparata model** [10]**.**
- **The results were object of several publications[6]** [8] [7]**.**
- **Notwithstanding Palladium is expensive, and shows various limitations.**

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[4] These experiments were performed below 100 °C.
[5] Experiments with plates were similar to those performed by A. Takahashi [20].
[6] Physic Letters A, Fusion Technology among others.

- **Its brittleness in particular negatively affects experiments with wires.**
- **In the last two decades the work shifted from the initial study of palladium based systems[7]; to nickel and its alloys.**
- **Constantan (Cu55Ni44Mn1) in particular is much cheaper than palladium, withstands temperatures as high as 900 C and shows AHE activity with deuterium and hydrogen.**
- **In fact, since 2011 hot Constantan[8] wires[9] became the focus of several experiments that leveraged on the unique set of properties of this alloy:**

1. **low cost**
2. **its remarkable capability to absorb hydrogen (T>150 °C)**
3. **high resilience in harsh experimental conditions**

[7] Initially only electrolytic experiments, after 2002 high temperature gaseous experiments in D_2, H_2, or their mixtures with Ar.

[8] It is unluckily Constantan may ever be subject to a monopoly, constrained, or limited supply. Similar alloys for instance are commonly used in the minting of coins.

[9] Wires are 100-200 cm long; 100-350 μm thick.

- **Heated Constantan shows indeed the occurrence of anomalous heat if a series of conditions are met:**

  A. **sufficiently high temperatures and large thermal gradients along the wire;**

  B. **the surface is roughened[10] and coated with Low Working Function (LWF) oxides;**

  C. **presence of a flux of atomic or ionised, deuterium or protium.**

In short, non-equilibrium conditions are compulsory to observe the occurrence of thermal anomalous effects, likewise to Pd based experiments.

- **The critical point for a practical application of thermal anomalous affects, is the need to minimize the extra energy added to the system in order to stimulate the "non-equilibrium";**
- **The ultimate goal being a useful power gain.** The Evolution of the experimental set up with Constantan wires[11] is shown in Fig. 1.

[10] Constantan wires require a procedure developed by our group [18] to make its surface porous and with a nanostructured texture of nickel-copper and LWF oxides.

[11] The experiments with Constantan performed at INFN-LNF were object of a recent review published by Elsevier [9]

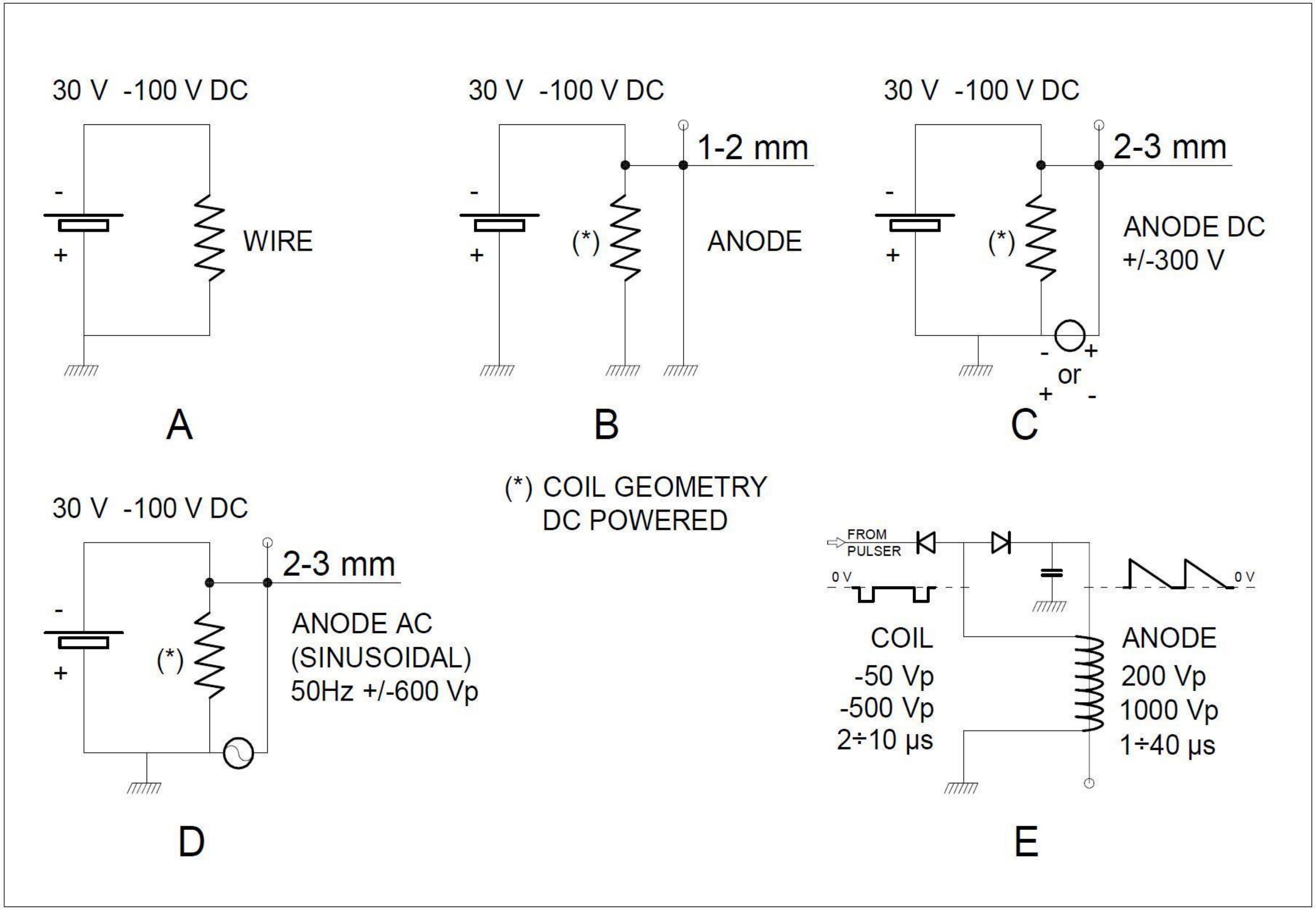

Fig.1. Overview of the evolution of our experimental set-up, 2011 (A, the simplest), the previous tested (D) and reported at ICCF22, ending with (E) discussed in this preliminary report.

Reactor's core geometry

On the base of the strong experimental evidence that non-equilibrium conditions are essential to obtain AHE, a new geometry of the reactor core was designed. The wire is arranged to fully exploit the power of pulses and their electromagnetic effects. This allows to use a longitudinal negative pulse to impulsively heat the wire, while generating a second positive pulse that is used for the breakdown of the gas among the cathode (Constantan wire) and the anode (iron tube on which the insulated Constantan wire is coiled).

The "in-situ" pulse generation, takes advantage of the short distance among the Constantan coil (that generates the positive pulse) and the iron core anode. This approach enables an effective energy transfer from extremely fast pulses, thus reducing the impact of impedance mismatching & parasite capacitive effects.

- **In addition, this allows to have a sequence, of thermal pulses[12], and an impulsive electro-migration in presence of a dielectric barrier discharge (or Paschen breakdown).**

[12] With a strong electron emission, i.e. Richardson effect [12].

To sum up, the reactor is based on a coiled coaxial structure with the inner core used as counter electrode[13].

The iron core acts as an anode enabling various operating regimes instrumental for the "non-equilibrium" of Constantan wires:

1. **Richardson operation mode:** in this case electrons are emitted by Constantan by simple thermionic effect.
2. **Paschen / Dielectric Barrier Discharge mode:** if the voltage of applied pulses and pressure are appropriate, a gas breakdown occurs. Previous experiments provided evidence that in this conditions the highest and longer lasting AHE can be obtained.

[13] The concept was introduced during ICCF22 Conference (8-13 September, 2019), Fig. 2 A, B [11].

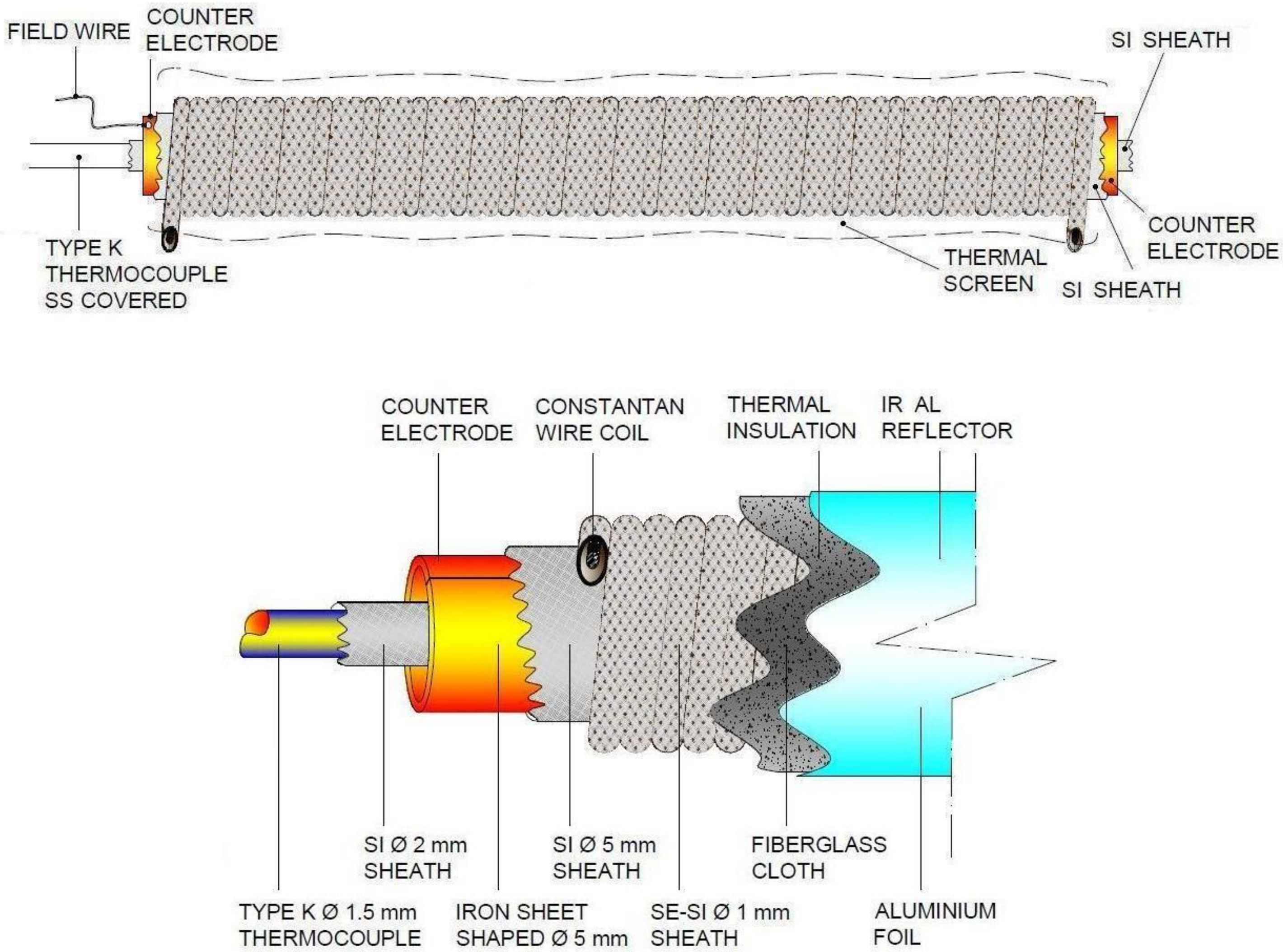

Fig. 2A. Scheme of the coaxial coil with its inner Fe counter-electrode. A coil has usually 75 turns.

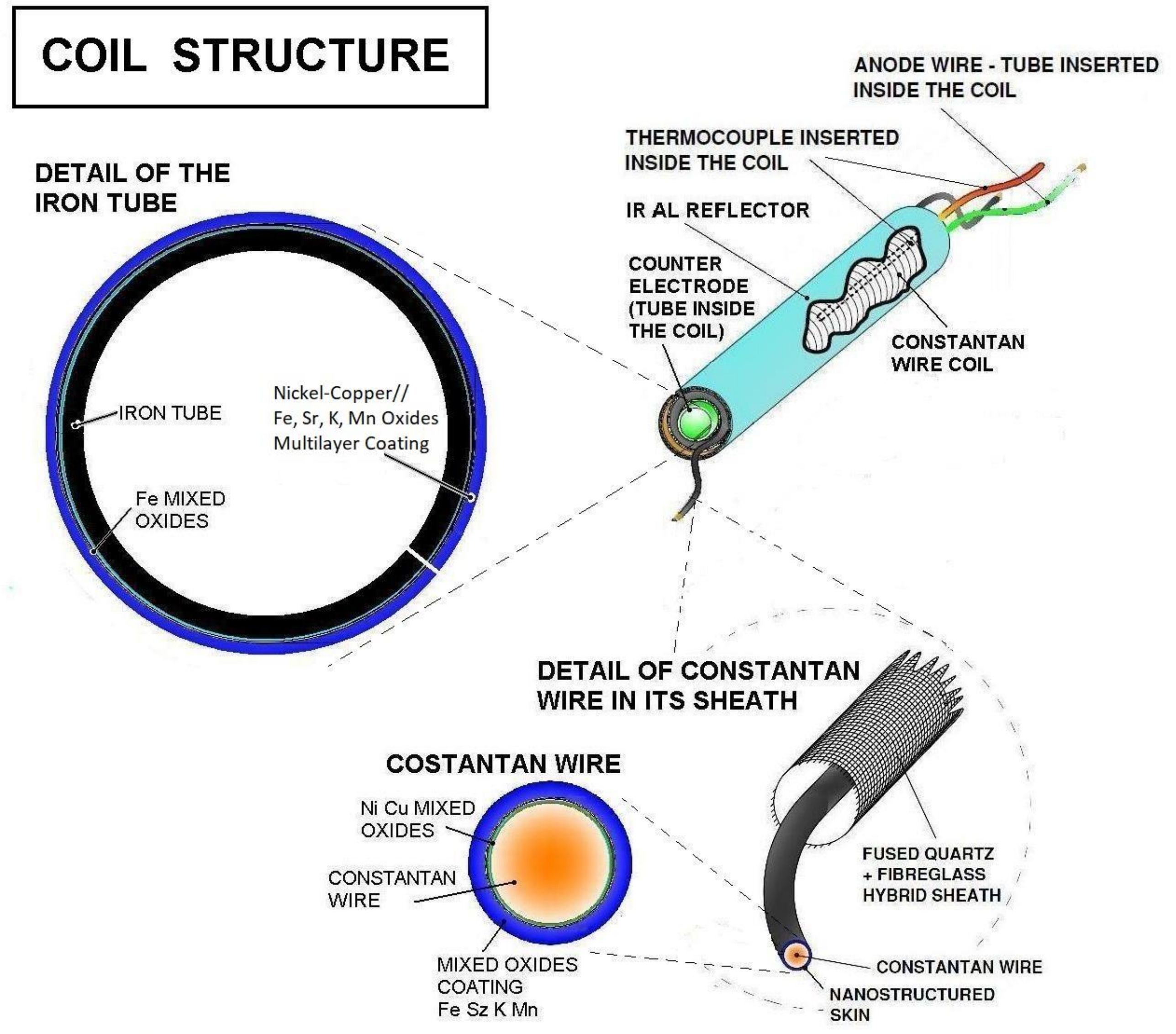

Fig.2B. Overview of the coil assembly comprised of a multilayer coating of LWF oxides; high temperature insulating hybrid glass-(Alumina-Quartz) sheaths; and an external IR reflector.

With respect to the circuitry used in previous experiments [11] **(ICCF22), the following upgrades were introduced:**

1. **In addition to a DC power supply[14], used to heat the wire to the operating temperatures[15], a pulsed power supply was connected in parallel.**

2. **The pulsed voltage-current, is expected to reach rather large peak values. For instance using a test coil[16] in air and room temperature, over 10000 V*A could be "injected" by the power supply without signs of damage.**

[14] Not shown.

[15] 500-700 °C.

[16] The test coil comprises a 350 µm, 160 cm long wire.

A) **The pulse duration can be varied from 0.5 to 10 µs. The current equilibrium time is about 2 µs when using a test-coil, due to the time constant of the coil itself. The repetition rate (RR) can be varied in principle up to 1000 Hz using the test coil as it is limited by the maximum steady state power that can be applied to the wire (about 120 W). The intrinsic limit of RR with short pulse duration, is as large as 30 kHz.**

B) **The impulses cause a large instantaneous increase of the wire temperature[17] and extremely large electro-migration values, in the order of 2-3 V/cm[18].**

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[17] With the 160 cm long, 350 µm tick wire it is about 130 °C with pulses of 10 µs

[18] Usually it is considered "large" an electromigration value of 0.5-1 V/cm.

C) **Moreover, because the coil geometry has intrinsically magnetic proprieties, we take advantage of the extra-voltage that arises when the current pulse is ended abruptly.** Considering the inductance of the coil (about 1.8 μH), the typical peak current applied to the coil (50 A), and the time of current opening[19], it is possible to get an over-voltage as large as 1100 V. This voltage is then sent to a "peak detector" circuit (D7 and C4 in Fig. 3) that collects it and sends it back to the counter electrode[20] (iron tube core).

[19] About 70-80 ns in proper conditions, this is work in progress.
[20] This can nearly be considered an "additional" in-situ pulser.

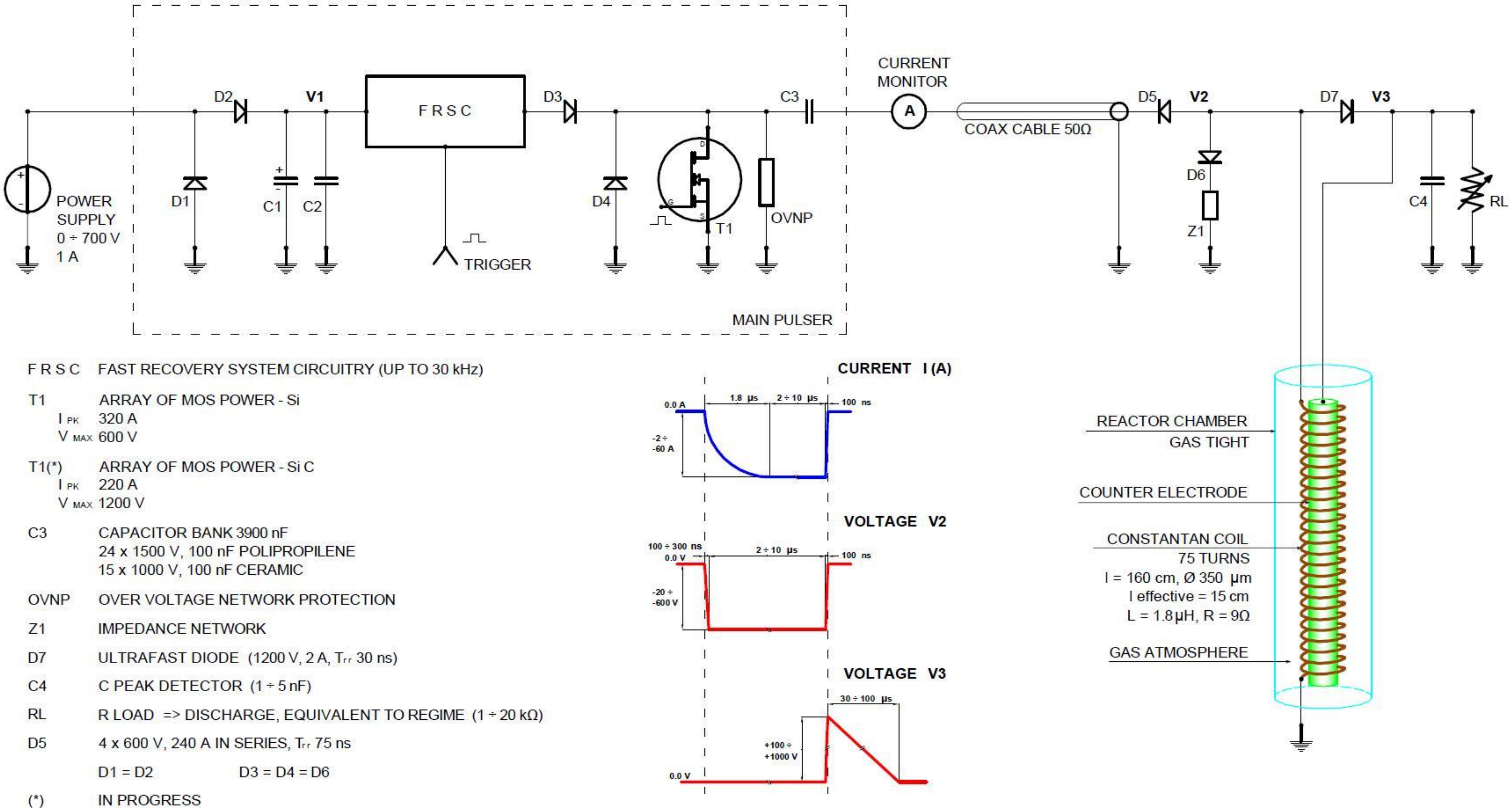

Fig. 3. Scheme of the assembly used to get negative high power pulses from the pulser (V2, I, up to 500 V, 50 A, 2-10 µs duration) and positive high voltage pulsed (V3, up to 1000 V). The pulse duration/fall is determined by the type of discharge mode among the electrodes (i.e. DBD and/or Paschen).

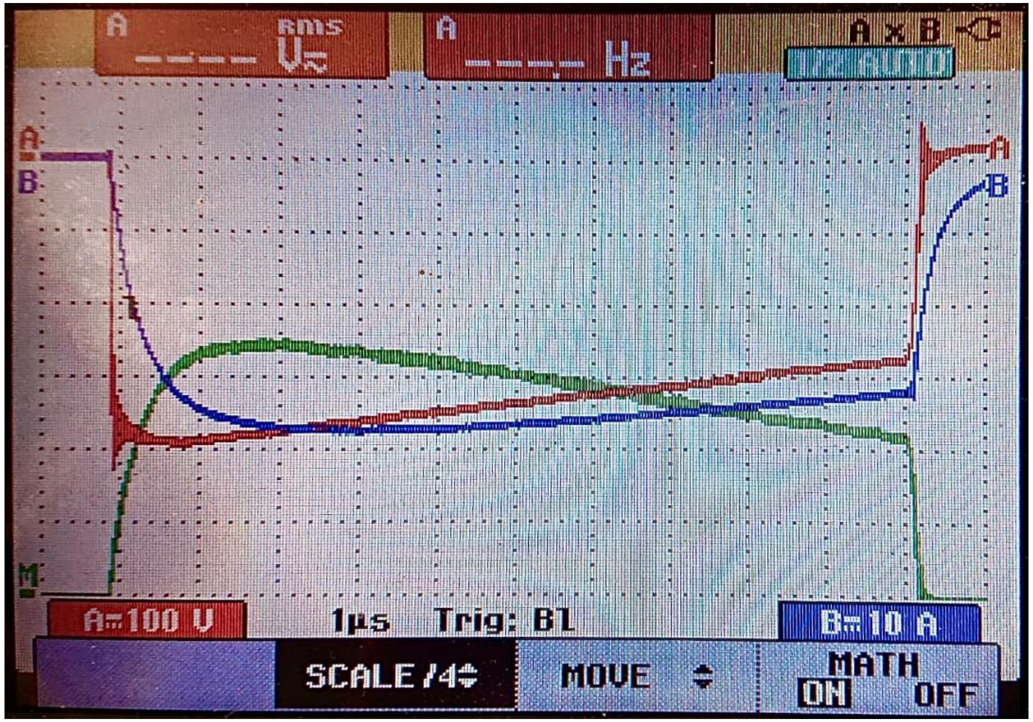

Fig. 4. Snapshot: Waveforms with Vdc=400 V for a Coil made of a 350 μm thick, 160 cm long wire. Pulse duration is 10 μs. Voltage (100 V/div), in red; Current (10 A/div), in blue. Pw in green, scale factor 4 → 4 kV*A /div.; peak power at 2 μs= 13.6 kV*A. The current rise time is about 2 μs (0→100 %).

[21] Typical pulse at high power section (V_PS=400 V). Test at NTP (normal, temperature & pressure) same geometry of the "true" coil.

Operating principles[22]

The reactor operating procedure is based on the application of various concurrent stimuli that were associated to AHE occurrence in previous experiments. The pulsed power supply and reactor assembly allows in particular to optimize the timing of the stimuli producing the non-equilibrium conditions. These are a consequence of the following effects:

- **The Richardson effect** [12] **occurs at high temperatures[23] and allows a continuous flow of electrons from the surface of a material. In our case the emission of electrons emission is increased at relatively low temperature thanks to a coating of low work-function oxides[24,25].** The dependence of current density on temperature and work-function of material surface is shown in Fig. 5.

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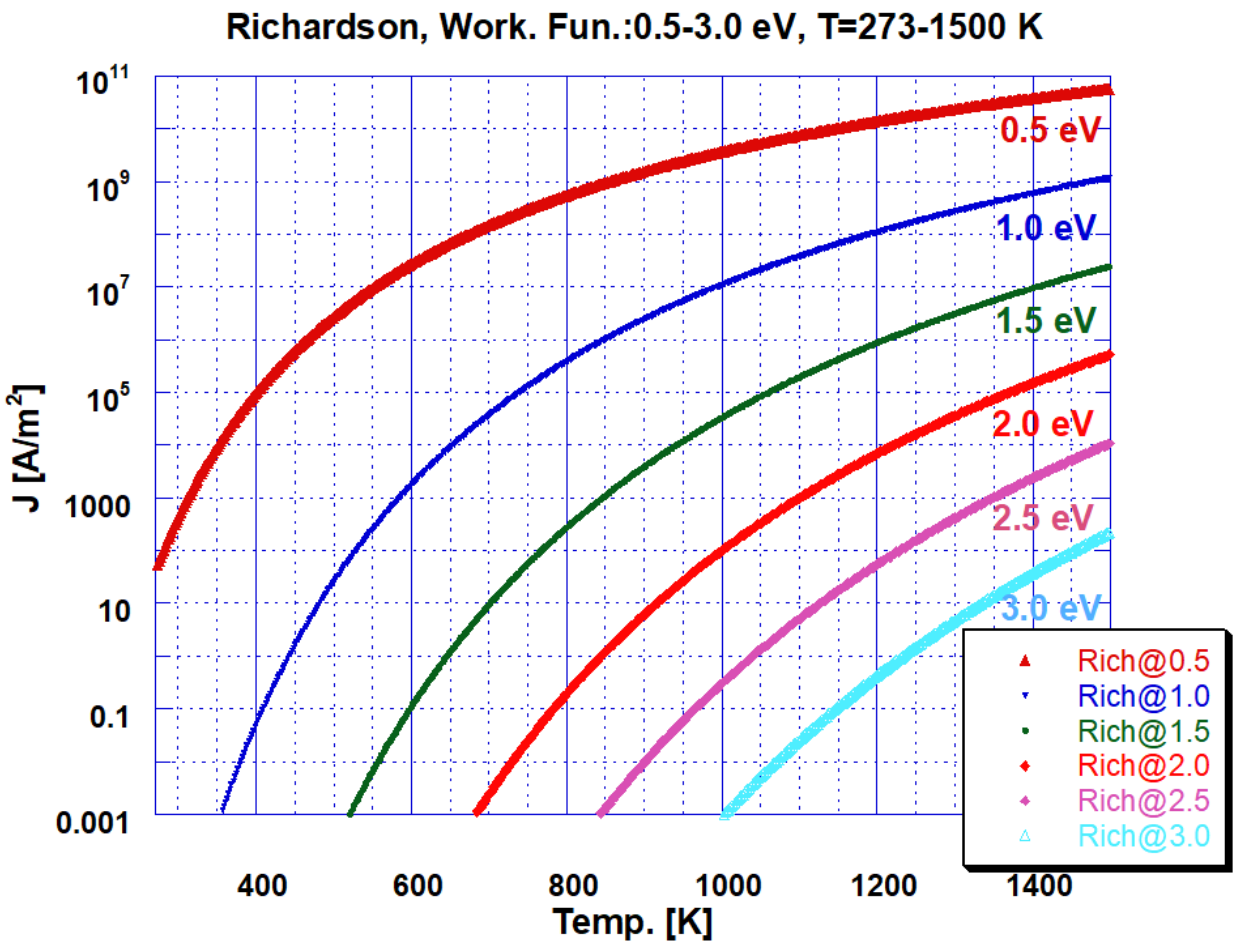
[22] Mediated by electromagnetic effects.

[23] To obtain a significant electron emission, Temperatures as high as 2000 °C may be needed.

[24] The use of LWF materials in LENR studies was pioneered by Y. Iwamura [17].

[25] Typical low work-function materials are oxides of alkaline-heart elements: BaO_2, SrO_2, CaO_2.



Electrons are emitted following the Richardson law for the thermionic emission at reduced pressure:

$$J = AT^2 e^{-\frac{W}{kT}}$$

Where:

J is the current density emitted (A/m^2)

T is the emitter temperature (K)

W is the work function (eV)

k is the Boltzmann constant (J/K)

A is a constant (in the simplest form of the law)

In our experiments, the current follows a trend analogous to the Child-Langmuir law:

$$B * S * \frac{V^{1.5}}{d^2}$$

where B is a constant, S is Anode surface, V voltage among Anode and Cathode, d their distance

Fig.5. Dependence of density of electron emission (A/m^2) on Temperature (273-1500 K) and Work Function (0.5—3.0 eV).

- **Child–Langmuir law. The electrons that "boil-off" at the surface of hot material at low gas pressures, can be expelled when a counter electrode with a certain voltage is positioned at a sufficiently close distance from the material surface.**
- **DBD or Paschen gas breakdow** [13] [14]**. The current of the discharge depends on the distance among electrodes, pressure and the type of gas. Figure 6 shows this dependence for a typical Paschen discharge, while Figure 7 shows schematically the occurrence of a DBD discharge on the surface of the wires, and possible effects on electron density.**
- With reference to the Paschen[26] Discharge curves shown in Fig. 6; we would highlight that the use of the low work-function oxides coating on the wires, and of a thoriated tungsten close to the reactor wall allows to significantly reduce[27] the breakdown voltage. We collected evidences in the experiments of 2019 [11] confirming that the thoriated tungsten is a useful enabler of Paschen discharges also in our experimental setup.

[26] The original formula was developed in 1889 by Friedrich Paschen (parallel plates and pure metals).
[27] Mostly due to Thorium gamma emission.

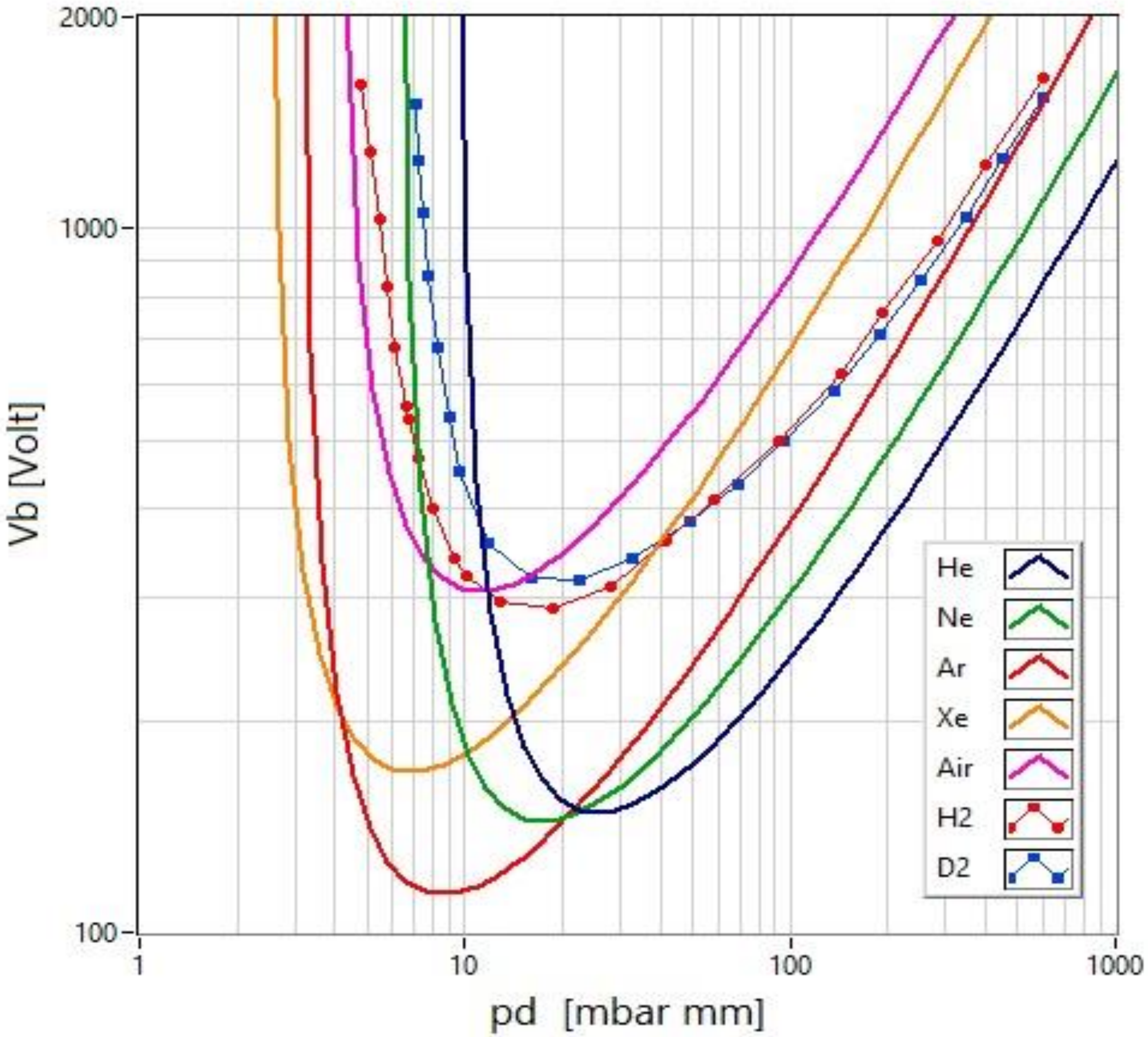


Figure 6. Direct current breakdown tension [14] (Vb) of several gases versus pressure and distance between electrodes (p*d). The addition of argon to deuterium clearly enables discharges at a lower voltage.

Some hypothesises on Constantan wires coated with low work-function oxides during a dielectric barrier discharge: the role of interfaces and interphases

The Dielectric Barrier Discharge (DBD) on wires coated with low conductivity oxides may trigger a series of phenomena summarized in Fig.7.

A speculative Sequence of events:

- **Electrons are emitted from the treated surface of the wire. During the pulse, they may accumulate at the interfaces or interphases between the deuterium/protium loaded wire and the coating of low work function mixed oxides[28].**

- **If the conditions are appropriate for a filamentary DBD discharge, further impulsive electron accumulation/depletion may occur.**

- **This accumulation is deemed responsible for localized impulsive changes of electron density.**

[28] The coating of low work function oxides is a dielectric at room temperature but it is deemed semi-conductive at high temperature.

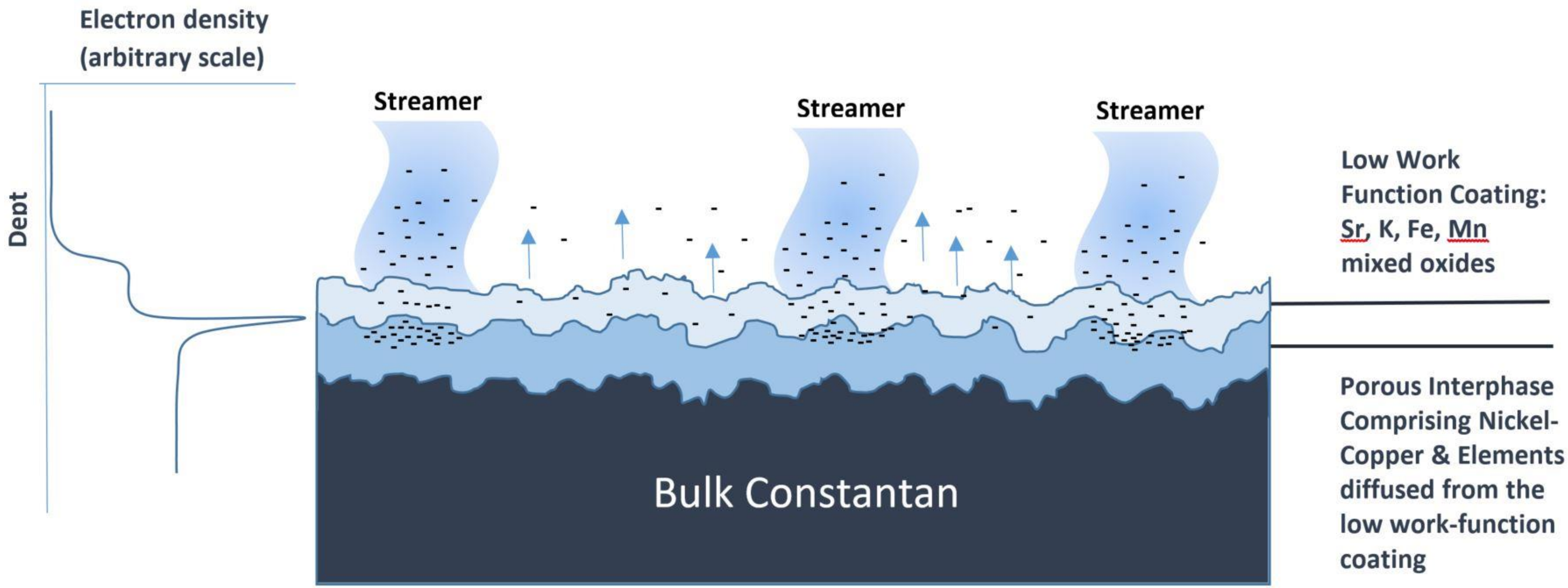


Fig. 7. Schematic drawing of the electrons behaviour during a negative unipolar pulse.

Hypothetical Effects:

- **We think that the changes of electron density at the interfaces or interphases of highly loaded materials are pivotal for the occurrence of anomalous thermal phenomena.**
- **Perhaps due to an enhancement of electron screening effects on nuclear fusion reactions and/or due to the formation of dense charge clusters and pico-metric structures** [15] [16]**.**

- **The presence of these interfaces and interphases are of extreme importance as they can mediate the occurrence of effective localized non-equilibrium conditions.**

A similarity of pulsed coil reactor with an Otto engine:

The Otto Engine working principle may offer an intuitive comparison with the process steps of the new power supply and reactor core design.

The specific arrangements of the circuitry, with its steps and their timing, remembers indeed the functioning of an Otto engine, where a spark-plug ignites a petrol-air mixture via an electric high voltage discharge. Similarly:

- **The high power long pulse (up to 10 µs), increases the temperature of low work-function oxides and initiates electrons emission[29].** This step is "comparable" to an almost adiabatic compression of air-petrol mixture.
- **The ignition step of a spark-plug corresponds instead to the ionization of the active gas among Constantan and counter-electrode[30,31].**

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[29] The high temperature of the wires initiates the electron emission by Richardson effect.
[30] Via a Dielectric Barrier or Paschen discharge modes.
[31] The used gases are: H_2, D_2; or their mixtures with Ar and Xe which decreases the voltage needed to initiate the discharge, while also lowering the thermal conductivity with respect to pure H_2, D_2 (thus increasing the process window of the reactor).

Conclusions

- **The proposed new setup and process, apart the required optimizations and adaptations, is based on the previous experience with palladium wires, both in electrolytic and gas-phase experiments.**
- **The energy gain, using thin and long wires of palladium, ranged between 15 and 30%** [8] **while some experiments showed values as large as 250%.**
- **The main drawback was the frequent break of the wires, due to an excessive brittleness of Pd after absorption of Deuterium.**
- **Moreover, the overall experiments duration was limited to few hours when highest energy gains were observed.**
- **The ionization in gas-phase systems by electric discharges was reported by our group at ICCF22** [11]**, but has not been investigated to the full potential, that is instead the focus of the new proposed experimental setup.**
- **The coaxial coiled Constantan set-up, preliminarily evaluated in experiments performed on June-September 2019** [11]**, showed clearly that AHE occurs mostly due "non-equilibrium" in the wires.**

- **This was proved already applying a mild 50 Hz sinusoidal excitation (voltage up to + - 600 Vpk at the counter-electrode).**
- **The new proposed setup is leveraging on the experience built since 1994 with high power pulses, and on a long series of experiments with Constantan, a very robust alloy that proved to withstand various experimental conditions and temperatures as high as 900 °C for several days.**
- **We are confident that the proposed setup, comprised of a multistep pulse excitation, may turn to be a significant step toward a practical application of LENR-AHE technologies[32].**
- **The current work is devoted to optimize the Paschen-DBD discharge modes, due to a very tight pulse timing at High Voltages.**
- **After several months of "heavy" evaluation[34] the pulsing on wires heated to a Richardson electron emission temperature[33] gave rather satisfactory results.**
- **The first results from the experimental setup object of this preliminary report are expected in Q2-Q3 2021.**

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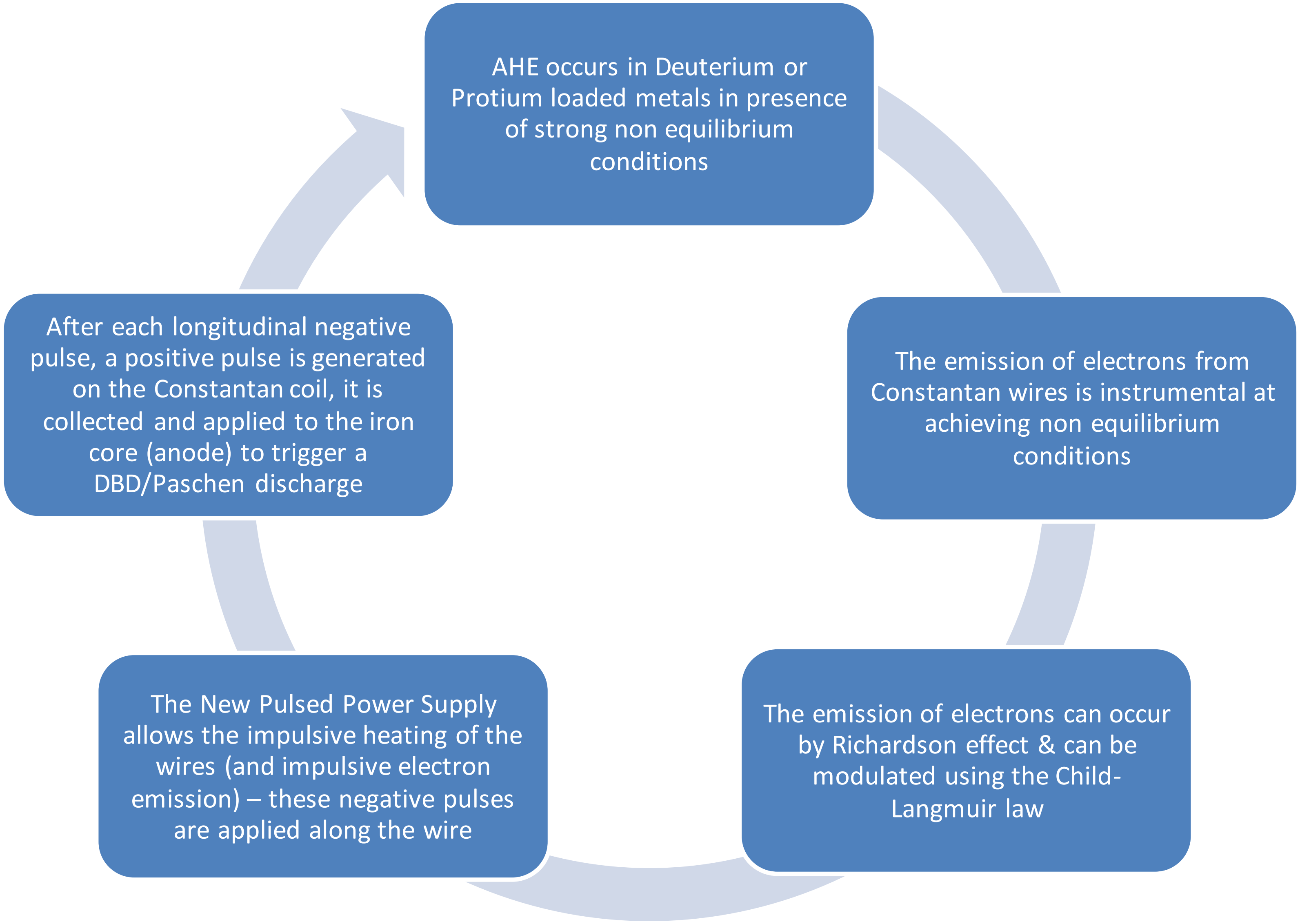
[32] Especially thanks to the modularity and flexibility of the new power supply configuration.
[33] On a test coaxial coil at normal temperature and pressure (NTP).

A Summary of the New Experimental Setup



ACKNOWLEDGMENTS

We are indebted to a Metallurgical Company in the North-Eastern part of Italy (NEMC), which since 2011 provided some financial support and performed key experiments in their own Laboratories (with their Scientist and Technicians). In fact, a fully independent cross-check of our most critical experiments was useful to increase the confidence on reported results.

We thank the International Fluid Association (IFA, based in Rome) for its partial support of costs for attending some Conferences, and for the fruitful technical discussions.

Since 2017 we initiated a collaboration with NEMC and SIGI-Favier (Italy-France), to design an original hybrid sheath obtained by crossing glass and Alumina–Quartz fibers, (these sheaths are used for the electric insulation of the wires). These original sheaths can continuously operate up to 1200 °C and, thanks to a tailored geometry, may adsorb significant amounts of Atomic Hydrogen[34].

We thank "Franco Corradi S.A.S." Company (Rho, Milan) as they provided high performance thin alumina tubes used for heavy-duty test up to 1100 °C.

Special thanks to the Scientists involved in the CleanHME European project, chaired by Konrad Czerski (Szczecin University, Poland). In particular, for the fruitful collaboration with Prof. Bo Hoistad and Collaborators (Uppsala University, Sweden) as well as with Dr. Andras Kowacs from the Company Broadbit.

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[34] Some types of glass, such as those used in our original sheaths, are able to adsorb atomic hydrogen at their surface, but not the molecular as discovered by I. Langmuir in 1928.

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