Electromagnetic excitation of coaxially-coiled Constantan wires by high-power, high-voltage, microsecond pulses.

#Francesco Celani[1,2,4], C. Lorenzetti[1], G. Vassallo[1,3], E. Purchi[1], S. Fiorilla[1], S. Cupellini[1], M. Nakamura[1], P. Cerreoni[1], R. Burri[1], P. Boccanera[1], A. Spallone[1,2,4], E. F. Marano[1].

(1) ISCMNS_L1, Intern. Soc. of Condensed Matter Nuclear Science_Via Cavour 26, 03013 Ferentino-Italy;
(2) EU Project H2020: CleanHME;-European Union;
(3) DIDI, University of Palermo, 90128 Palermo (PA)-Italy;
(4) Istituto Nazionale di Fisica Nucleare, Via E. Fermi 56, 00044 Frascati (RM)-Italy.

****

E-mail: franzcelani@libero.it INFN-LNF, Via E. Fermi 56, 00044 Frascati (RM)-Italy

ICCF23: June 9-11, 2021; Xiamen University-China

OUTLINE extended

- **Our pulse approach and the study of anomalies in Hydrogen and/or Deuterium-Metal systems.**

  # From LiOD-D_2O electrolysis of precious metal Pd (40-60 °C, *PLA 214, 1996*) to recent (JCMNS 33, 2020) gas phase experiments with low cost Constantan (Cu-Ni alloy) up to 800 °C.

- **Overview of the Techniques that we explored (since 2018) to induce AHE (Anomalous Heat Effects) by varying temperature, gas pressure, voltage and distance among electrodes:**

  # Richardson,

  # Child-Langmuir,

  # Paschen/DBD

- **Recent progresses, starting from our "original" coaxial wire geometry, of the reactor core and related operating regimes (ICCF22, 8-13 Sept. 2019, Assisi-Italy):**

 # Details on the treated Constantan (submicrometric coating with Low Work Function materials), powered by large longitudinal DC with counter-electrode providing transverse mild excitation (few mA, ±600 V, 50 Hz sinusoidal).

- **NEW. Particulars of high power, fast rise-time, pulse excitation to induce large *non-equilibrium situations*, i.e. *flux of active gas* *both* at internal bulk and surface:**

  a) large longitudinal electromigration and surface current density (skin effect);

  b) possibility of Constantan sub-micrometric surfaces activation by transverse plasma ionization of active-noble gas mixtures (in progress);

  c) possible phonon excitation?

- **Recent results (work in progress!!) and near-future experiments: *achievements* (some, very *useful, unexpected*) and problems/drawbacks.**

[Bkg] The origin of the "pulse" approach. [Bkg]

(*Bkg=> Background information*; further details allowable at DOI: 10.13140/RG.2.2.31545.90720)

Since 1994 electric pulses, both transversal and longitudinal (different t/l ratios, depending on specific geometry adopted), were pioneered by us in mild temperature experiments, i.e. electrolytic environments, on plates and wires made of Palladium and its alloys (like Pd-Y).

- **The use of pulses aimed, mainly, at enhancing the effects of Electromigration of deuterium or protium. Moreover, pulses were, and are, sources of strong NON-EQUILIBRIUM to the system.**

- **The whole program of the time considered, apart the well-known (since 1928, Alfred Coehn and Collaborators) Electromigration effects of protium, even the occurrence of "Coherence" as per Giuliano Preparata's model. Such kind of experiments considered only DC condition: maximizing V/cm ratio, in the case of Cohen experiments; the whole voltage drop along the wire, in the case of Preparata experiments (under the strict condition to have gotten "*coherence*" of the whole wire).**

- **In comparison, using both DC and later-on pulsed stimulations, our results were the object of several publications (among others: PLA 214, 1996, 1-13).**

- **Notwithstanding Palladium is expensive, and shows various limitations: its large brittleness, after H or D absorption, negatively affects experiments with thin wires (the best geometry to maximize and observe electromigration, or coherence, phenomena) and their time duration.**

- ***In the last two decades the work shifted from the initial study of Palladium based systems (dc and pulsed) to simpler,*** **and less complex and costly,** ***dc experiments using Nickel (2002) and its alloys (since 2011), pure and/or covered by other elements, usually multilayer structures.***

- **Constantan ($Cu_{55}Ni_{44}Mn_1$) is much cheaper than Palladium, withstands temperatures as high as 900 °C and shows AHE activity both with deuterium and hydrogen.**

- **As consequence since 2011 hot Constantan wires 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 dissociate, from molecular to atomic state, and absorb hydrogen (T>150 °C) keeping it inside also at high temperatures (700 °C);**
    3) **High resilience in harsh experimental conditions.**

Heated Constantan wire show occurrence of anomalous AHE if, once "*activated*" (i.e. *the most difficult task to be achieved*), a series of conditions are met:

A) **Sufficiently high temperatures and large thermal gradients along the wire;**

B) **The surface is roughened and coated with Low Work Function (LWF) oxides;**

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

In short, *non-equilibrium conditions, together with their several physical-chemical techniques, are necessary to observe any of the anomalies, including the thermal anomalies, which are similar to the usual Pd-based experiments.*

The critical points, for a practical application of Anomalous Heat Effects (AHE), are:

- **To find a reliable/simple procedure to "*activate*", and keep stable over time, the specific "metal" (or alloy) able to be the key co-factor for AHE production.**

- **To find a simple procedure to "*renew*" the material *in-situ*, counteracting the usual "aging effects", e.g. well known on the specific materials (usually Fe, Ni, Cu, Mn, K) used for catalytic reactions. We note that most of them are used in the core of our reactor.**

- **The need to *minimize the extra energy added* to the system in order to stimulate the "non-equilibrium": the ultimate goal is useful power gain. In other words, the total balance of energy needed to get useful AHE→*from the well to the wheel*, using automobile terminology.**

The evolution of the experimental set up, with Constantan wires, is shown in Fig. 1.

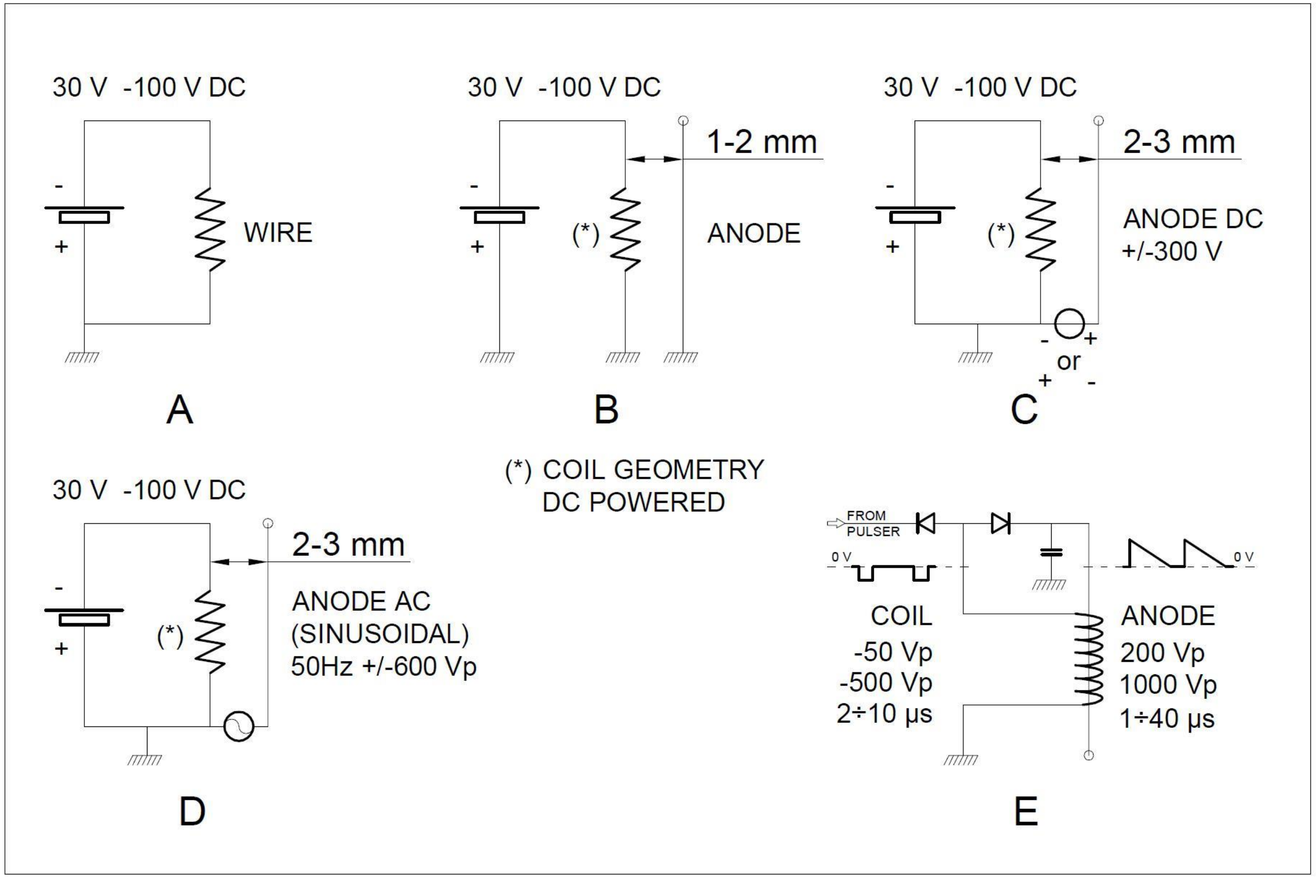

Fig.1. Overview of the evolution of our experimental set-up: 2011 (A, the simplest), the previous tested (D) and reported at ICCF22, ending with (E) discussed in this report. i.e. work in (fast) progress→further improvements/changing, day by day. Fig. E is just the situation at February 2021; on May further details were changed because both new side effects discovered and improving of HV time-pattern.
Overall main operating conditions, apart from aging problems at Cathode, depend on: ***core geometry, wire diameter, gas pressure and type, maximum peak voltage allowable at the Anode, operating temperatures.***

[Bkg] Reactor's core geometry *[Bkg]*

On the base of the strong experimental evidence that, among others, 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, as following:

A) **First, *High-Power longitudinal negative pulses* impulsively over-heat mainly the wire surface. Combined effects to get large skin effect because: very fast-rise time and short pulse duration; magnetic material at the surface=> $\delta=(\rho/(\pi*\nu*\mu_r*\mu_o))^{0.5}$. Final result is the "boiling-off" of the *electrons* (like *plasma*) emitted by Low Work Function material covering the sponge Constant wire➔*Richardson* effect.**

B) **Second, self-generating *High Voltage-Low mean Current positive pulse.* It is used both for accelerating the electrons toward the anode (*Child-Langmuir* effect) and induce the breakdown of the active gas (*Paschen/DBD* effects) among the cathode (Constantan wire) and the anode (iron tube on which the insulated Constantan wire is coiled). The glass insulation sheath is NOT complete but micro-holes shaped.**

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

- **In addition, this allows to have a sequence of thermal pulses able to increase electron emission when the temperature is appropriate for Richardson effect of the Low Work Function (LWF) materials (multilayered mixture of Sr, Fe, K, Mn) coating the wire. The multilayer structure in LENR was pioneered by Yasuhiro Iwamura-Japan, since 1998.**
- **All together they are starting points for a *longitudinal* impulsive electro-migration, apart huge phonon effects (to be explored in the near future), with even diffusion speed of Hydrogen increased just because higher temperatures, in presence of also a dielectric barrier discharge (or Paschen breakdown).**

In conclusion, the *reactor* is based on a *coiled coaxial structure* (made by sponge Constantan wire with surface coated by LWF materials) *with the inner core used as counter electrode*. Its schematic, and detail, are shown in Fig. 2A, 2B.

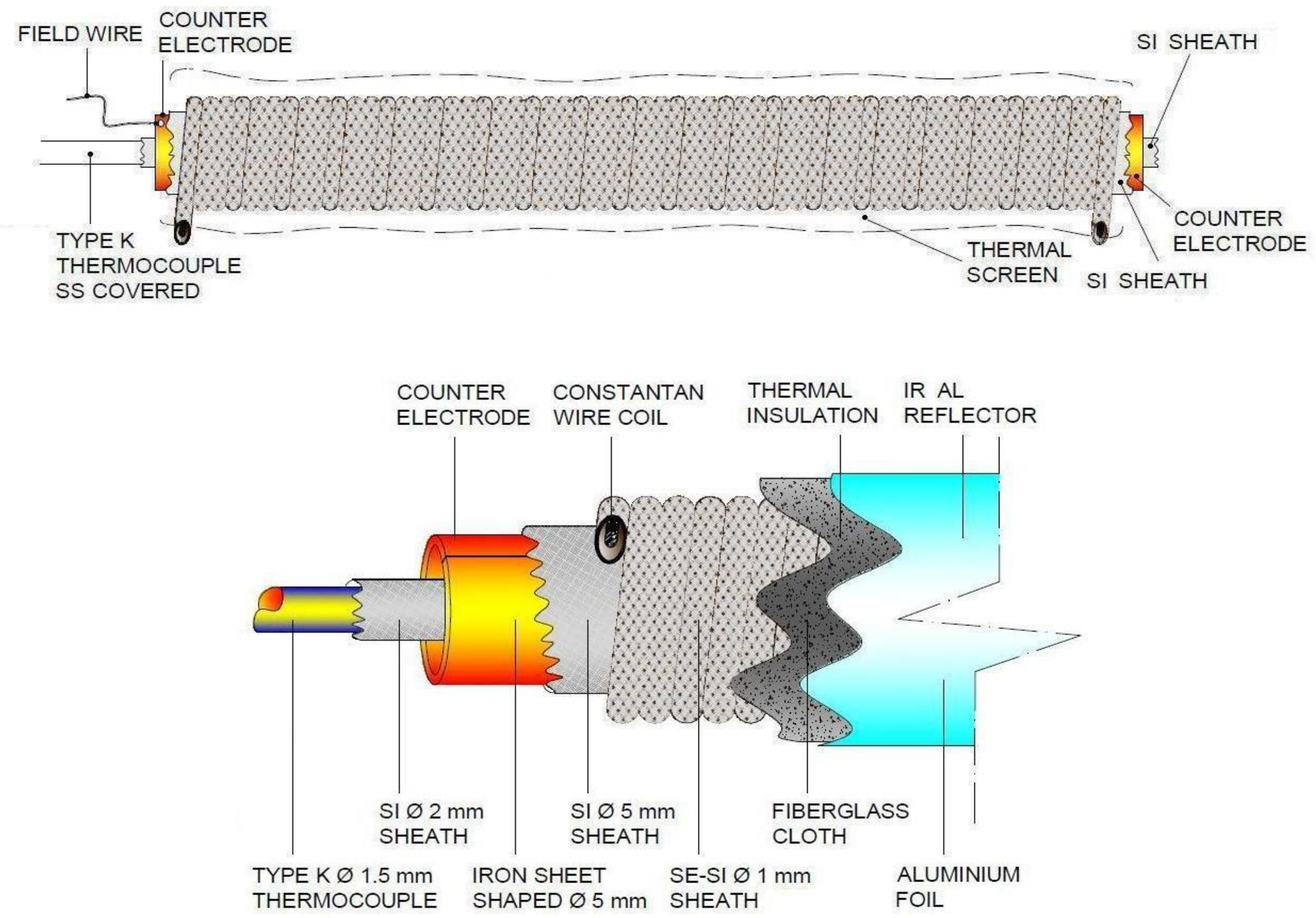

Fig. 2A. Scheme of the coaxial coil with its inner Fe counter-electrode. A coil, length of 158 cm, had usually 75 turns; recently reduced to about 50 because HV insulation problematics.

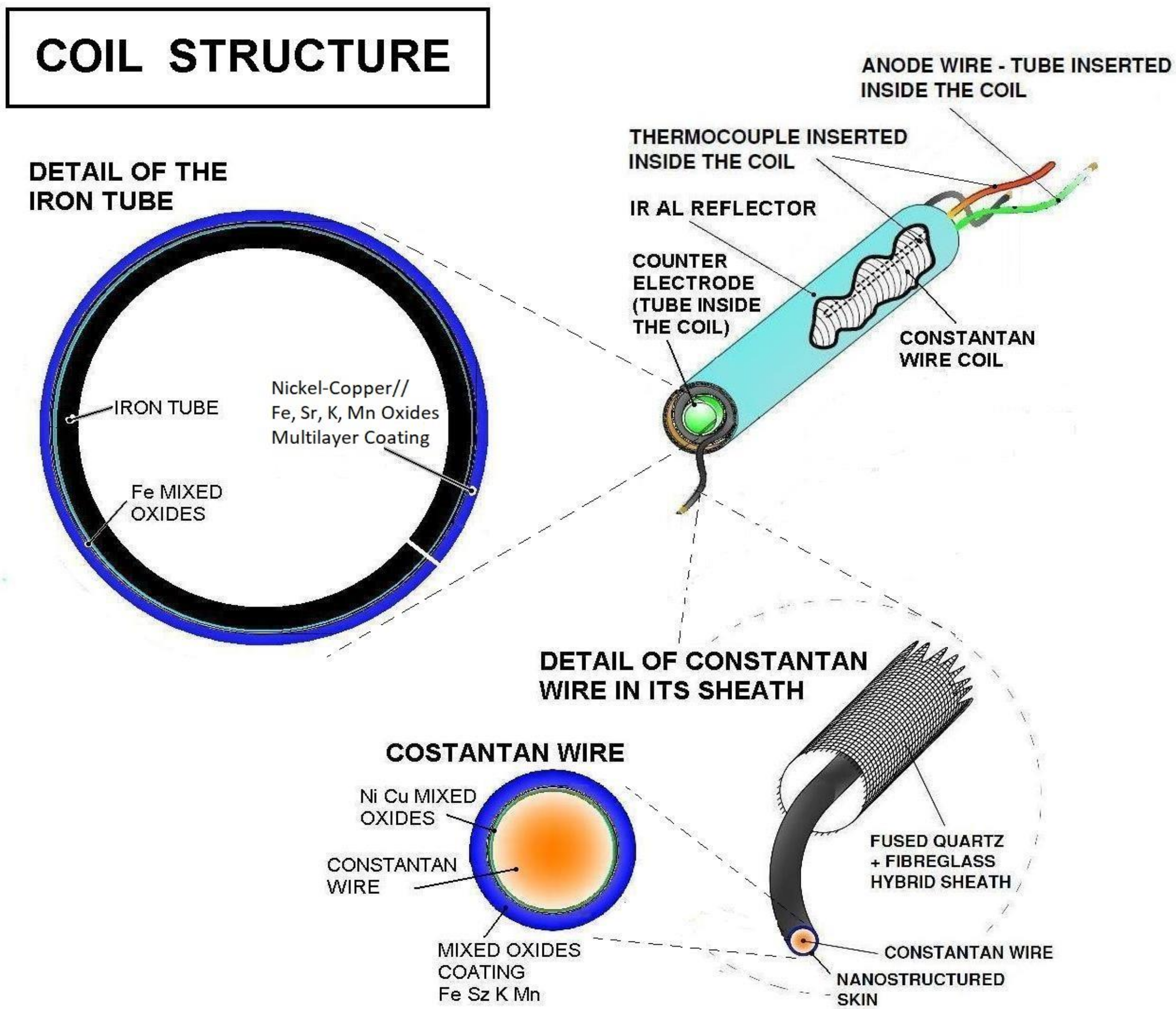

Fig. 2B. Overview of the coil assembly: multilayer coating of LWF oxides; high temperature insulating hybrid glass-(AlO_2-SiO_2) porous sheaths; external IR reflector.

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

1.Richardson operation mode: electrons are emitted by Constantan by simple Thermionic effect. The anode is almost disconnected: low voltage in respect to cathode, also movement of electrons at surface are at low values, just "boiling off" at the surface (Child-Langmuir: current flowing depends on voltage as $V^{1.5}$).

2, 3. Child-Langmuir; Paschen/Dielectric Barrier Discharge modes: if the voltage of applied pulses and pressure are appropriate, a gas breakdown occurs. *Previous experiments, shown at ICCF22, provided evidences that in these conditions the highest and longer lasting AHE can be obtained.*

A) Resuming: the impulses cause, for each pulse injected:

- **large instantaneous increase of the pre-heated surface wire temperature (estimated to be up to 150 °C in optimised conditions);**

- **extremely large electro-migration values, of the order of 2-3 V/cm, as measured by a 100 MHz digital oscilloscope during pulse conditions. Used also another, 200 MHz BW analogic, for cross-check purposes.**

B) One of key parameter for “in-phase” operations, i.e. the delay from the end of powerful Richardson regime and the time to get the High Voltage (to start the Paschen/DBD regime), was measured to be <100 ns. Moreover, the rise time of HV pulses is of the order of several kV/μs. Such values are proper for our purposes.

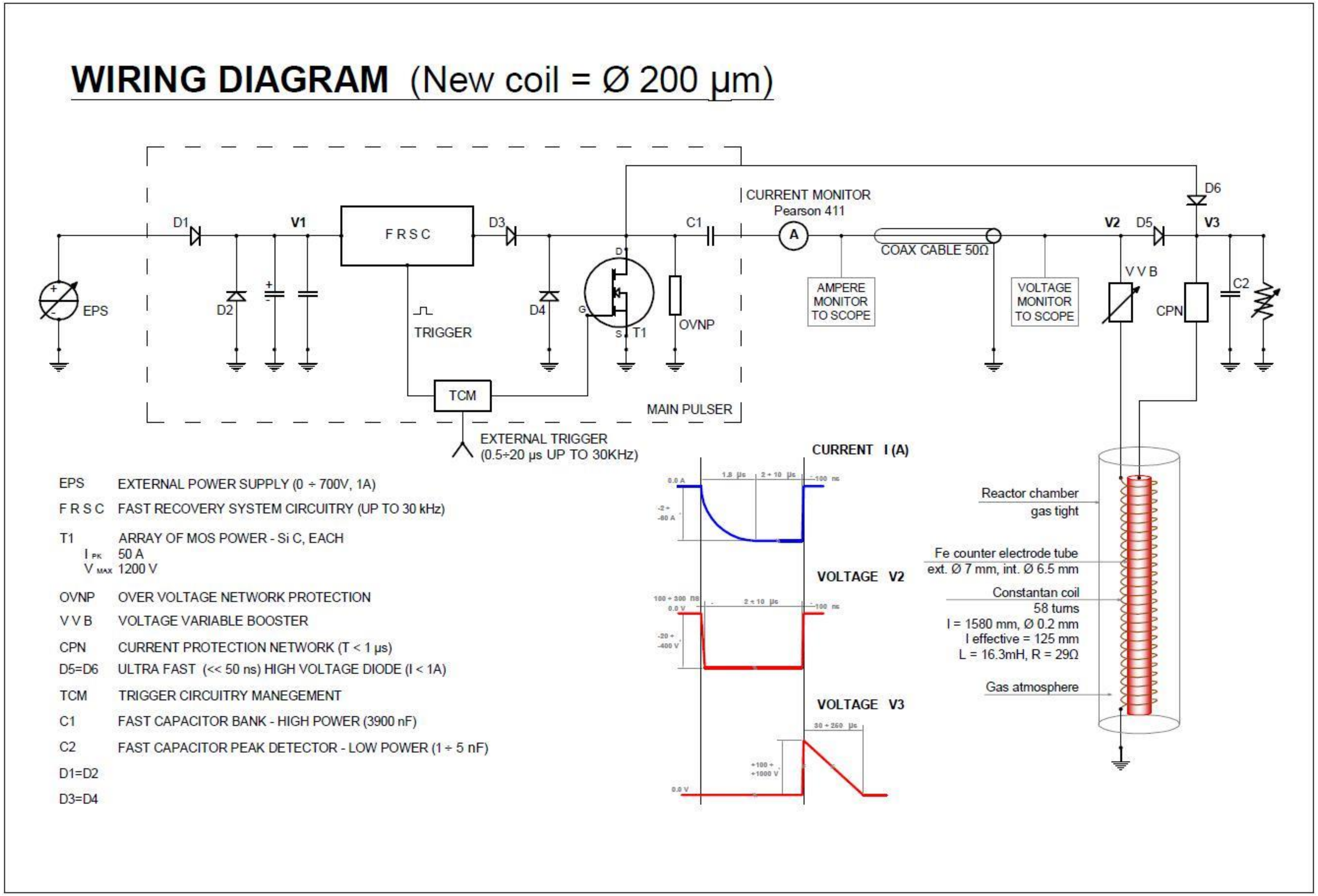

Fig. 3. Schematic of the pulser with main auxiliary circuits, depicted as "black box".

Pulse duration/fall (V3) is determined by the discharge mode along the electrodes (i.e. DBD, Paschen).

[Bkg] Operating principles [Bkg]

The reactor operating procedure is based on the application of various concurrent stimuli that were associated to AHE occurrence in previous experiments (like ICCF22).
The "new" pulsed power supply and reactor assembly allows in particular to optimize the timing of the stimuli producing the non-equilibrium conditions. As anticipated, these are consequence of the following effects:

1) **The Richardson effect occurs at high temperatures and allows a continuous flow of electrons from the surface of a material. In our case, the emission of electrons is increased at relatively low temperature thanks to a coating of Low Work Function oxides. The dependence of current density on temperature and work function of material surface is shown in Fig. 4. With the LWF materials from us adopted, the usual values are 1.9--2.3 eV.**

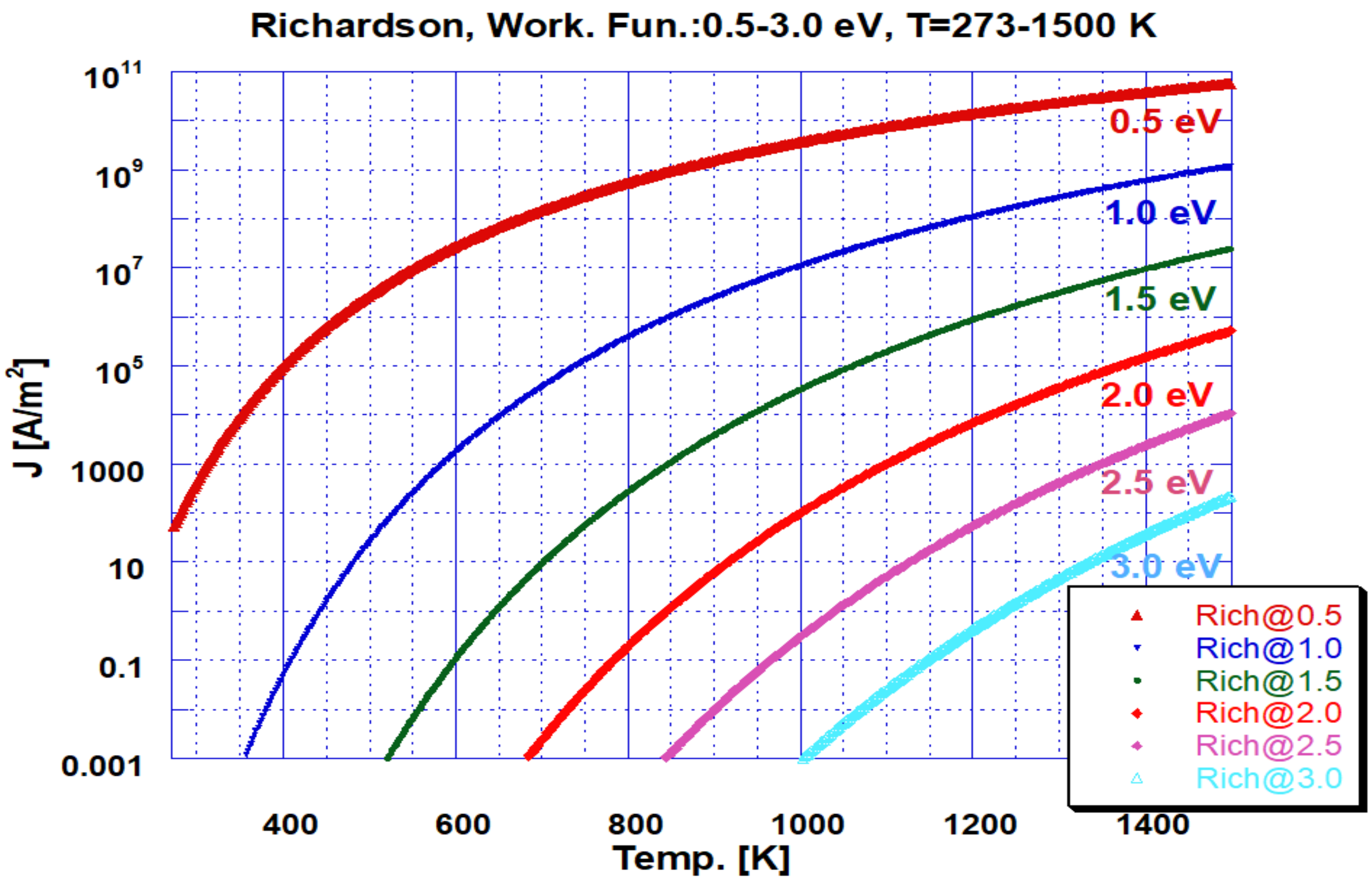

Fig.4. Calculated dependence of density of electron emission J (A/m^2) on Temperature (273-1500 K) and Work Function (0.5—3.0 eV), according to the Richardson law. Because specific treatments at the wire surface, sponge like, the effective surface is about 100 times larger (SEM observations): in the case of our 200 μm diameter, 158 cm long wire, it increases from 10^{-3} to 10^{-1} m^2. With W=2 eV, J is 10^1 at 730 °C and jumps to 10^3 at 980°C. ***Both temperature and W dependences are very large on J.***

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, 1.38*10^{-23} (J/K);**
- **A is a constant (in the simplest form of the law: 1.20173*10^6 A*m).**

From the formula it is evident the need to have values of *W as low as possible* to avoid operating temperatures excessively large (over 1000 °C). In our experiments we used mainly SrO, K doped, to have a value of W close to 2 eV. All the wire pretreatments (i.e. surface oxidation→reductions to get submicrometric sponge-like surfaces, i. e. large effective area) and multiple chemical coatings (multilayers procedure), are home-made.

2) 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. The current intensity depends as $V^{1.5}$.

In detail:

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

Where:

- **J is the current density,**
- **B is a constant,**
- **S is Anode surface,**
- **V is voltage among Anode and Cathode,**
- **d is Anode-Cathode distance.**

- **DBD or Paschen gas breakdown. The current of the discharge depends on the distance among electrodes, pressure and the type of gas. Figure 5 shows this dependence for a typical Paschen discharge, while Figure 6 shows, very schematically, the occurrence of a DBD discharge on the surface of the wires, and possible effects on electron density.**

- **With reference to the Paschen discharge curves (Fig. 5) we would highlight that the use of the LWF oxides coating on the wires, and of a Thoriated Tungsten ($WTh_{5\%}$, bundle of 2 mm diameter long rods, inside a SS airtight thin-wall tube) close to the glass reactor external wall, allows a significant reduction of the breakdown voltage because γ emission. In the experiments of 2019 we collected evidence confirming that the Thoriated Tungsten is a useful, and safe-simple, enabler of Paschen discharges also in our experiment set-up.**

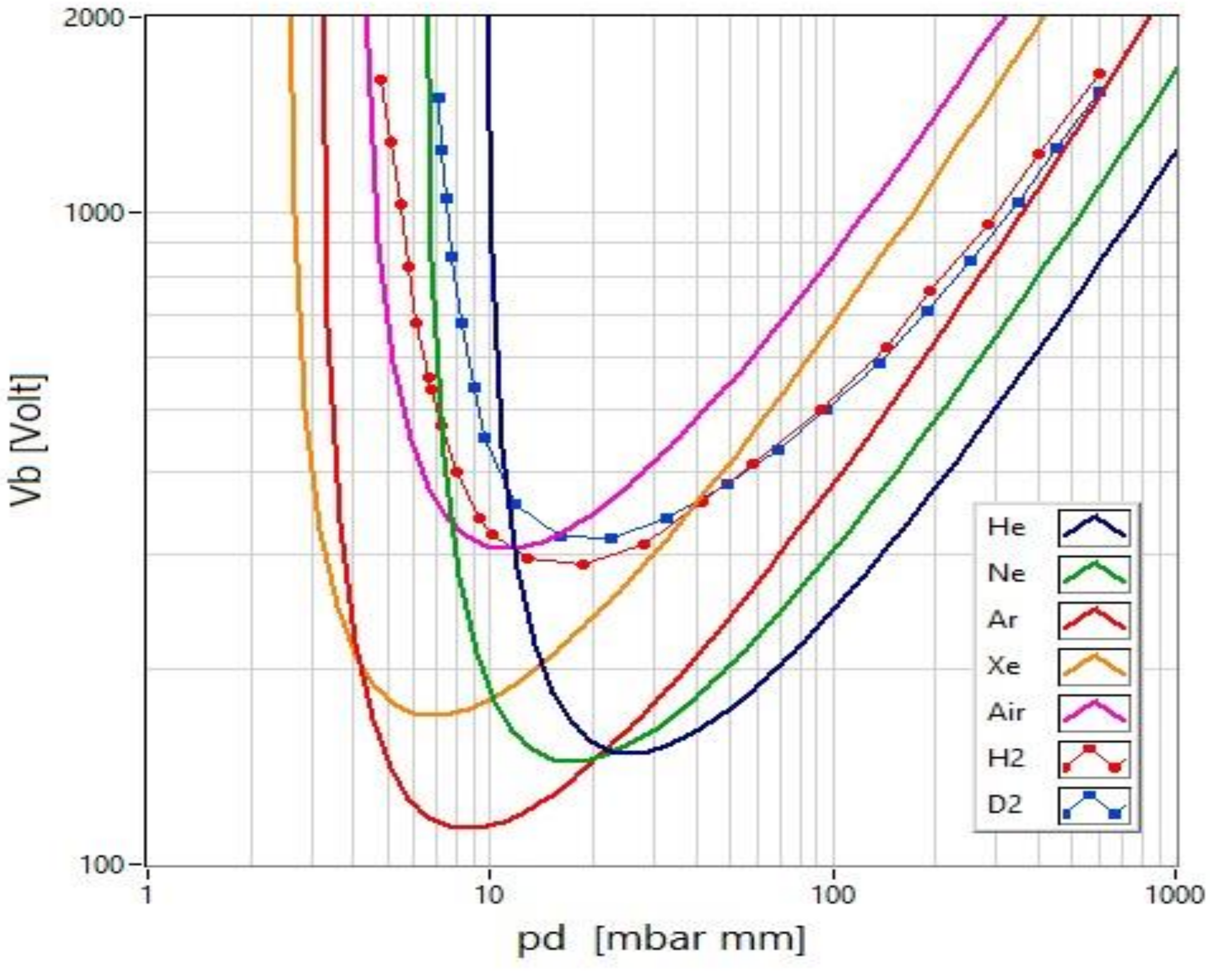

Figure 5. Direct current breakdown tension (Vb) of several gases versus pressure and distance between electrodes (p*d). The addition of Ar to H_2 or D_2 clearly enables discharges at lower voltages. He could be useful at higher values of p*d.

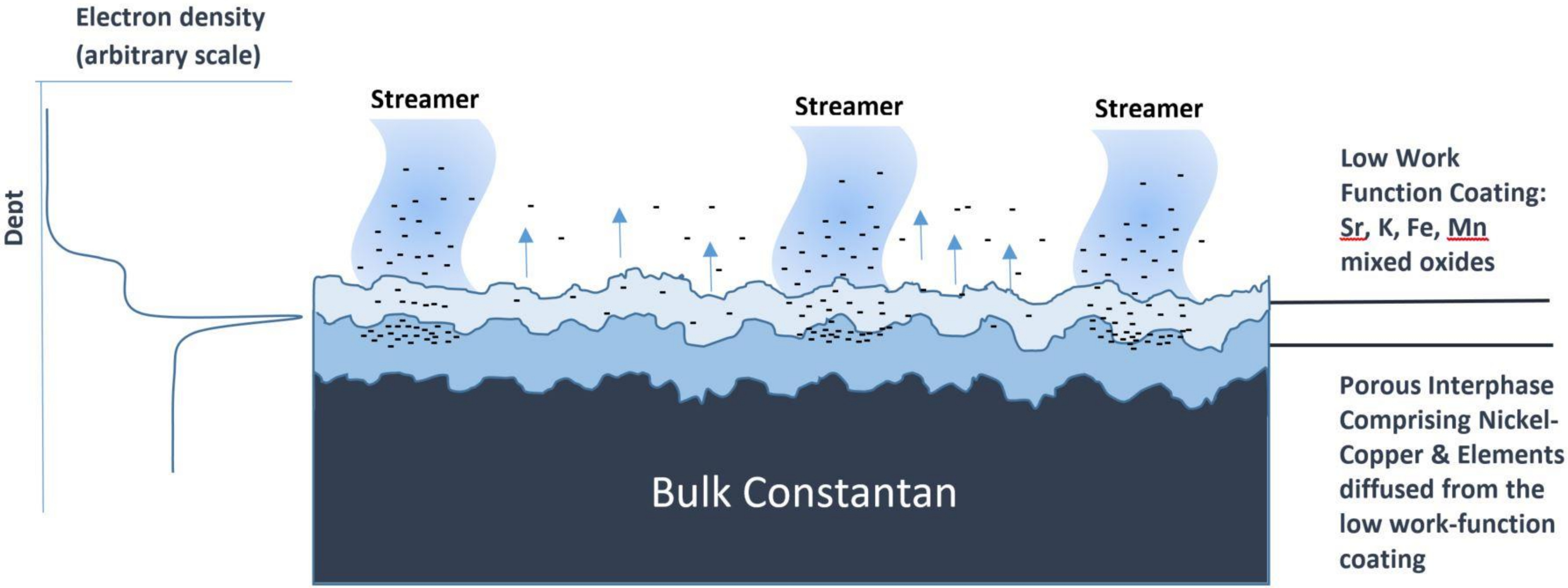

Fig. 6. Schematic drawing of the electron behaviour during a negative unipolar pulse.

Recent results using pulsed power

- **Since March 2021 the main improvements made to the pulser, to "match" the unusual needs of coiled coaxial core, with magnetic materials both at the wire surface (Fe_xO_y) and at the inner section (Fe tube), were satisfactory for the planned heavy-duty test. The pulser was designed according to the principles of "capacitive discharge" and is characterized by an unusual (proprietary) high-efficiency, even at quite large repetition rate (up to 30 kHz; specific circuitry labelled as FRSC in Fig. 3).**

- **In particular, the new unconventional procedure to "generate" useful (i.e. under control) high voltage at the end of main power pulse was tested for long times without failure of electronics, even in the most severe operating conditions *($\Delta V/\Delta t$ of the order of 5-10 kV/μs*, up to 2500 Hz of the present repetition rate).**

- **Moreover, thanks to the very high frequency performances of the main high-power switch adopted (SiC technology), the commutation losses were kept at very low values, increasing the *overall efficiency of the pulser (close to 90%) and long-time reliability*.**

- **Among others, because observation of some of the experimental results, we were induced to increase the maximum operating repetition-rate from 1 kHz (as planned at the beginning of the CleanHME project) up to 2.5 kHz. Again, apart the time spent to modify the design, no damages to the circuitry and/or to the Constantan wire, at enough high gas pressures, were observed.**

- **The "useful" maximum peak power up to now applied to the Constantan wire (l=158 cm, Φ=200 μm, weight about 450 mg) was over 4500 V*A, i.e. over 10 kV*A/g of material. The overall time duration of the pulse was kept, at the moment, at 10 μs. We have indications, based on short-time previous test, that it could be possible to increase the peak power up to over 30% of the present situation.**

- **The effective mean power is about 80% of the peak power because inductive effects of the coil, magnetic core included (rise-time of the pulse is limited by the value of L/R).**

- **The electromigration effect by itself, and local heating of the wire by longitudinal current flowing, to provide mean power up to about 95 W, was successful: no damages even after 60 h of continuous operations at 2.5 kHz of repetition rate. The measured inner coil temperature was close to *600 °C* when we adopted H_2 gas largely enriched by Ar ➔*Ar/H_2=84/16*. We reduced the losses to RT just by insulating proprieties of Ar.**

- **The SIMPLE glass reactor, at the moment just dissipation type (thermal equilibrium time <30 minutes), worked properly for our purposes and was possible even to make some, enough accurate, thermometry using several "blanks". We used only 2 thermocouples, K type (max temperature 1200 °C), SS covered (external body grounded to minimize possible RF interferences) and electrically insulated. The first temperature is put into the centre of the coil (T_int.), the second at the external wall (T_ext.) of the borosilicate glass reactor (3 mm thick): the type, since 2011, used in our experiments.**

- **In the near future, once we obtained enough satisfactory results in the whole, we will move to usual air-flow calorimeter (equilibrium time about 4-6 hours), operative in the Frascati Laboratory (e.g. paper at ICCF22, published by JCMNS 33, 2020, pg. 1-28).**

- **All the test at enough *high pressure (some bar, i.e. far from Paschen regime*) of gas (He, H_2, Ar-H_2) used were successful. Also test under dynamic vacuum were successful.**

- **When we tried to enter into Paschen/DBD regime, i.e. lowering the pressure step-by step (from 4-5 down to 0.1 bar, or lower), under high voltage pulsed situations (about 1000 V), we experienced several catastrophic failures of the coils.**

- **As anticipated, we didn't observe catastrophic failures in the case of operation under full dynamic vacuum. Adopted the procedure of before making vacuum (dynamic!!) and after giving High Pulsed Power. About pumping, a usual 2-stages rotary is enough: not necessary a TMP type. Just keep attention to avoid contamination by oil vapours.**

- **The most probable reason of breaking, according to visual observations, were localized, high voltage (about 1000 V peak), discharges.**

- **The simplest explanation is that the Paschen regime is excessively "severe" to the thin wire used (Φ=200 mm) in our present experimental conditions.**

- **Up to now we changed 5 coils. We make some changing on the geometrical construction details but they were, at the moment, not enough to solve the drawbacks.**

- **Even the addition of some protection network, shown as CPN black box in Fig.3, to limit the "long time" (>>1 μs) current flowing among electrodes, was not enough to solve the problem for a long enough time (at least 30 minutes, i.e. the equilibrium time of the system) of operations.**

- **Waiting for some new idea/devices to make more homogeneous the electric field among the electrodes, we studied deeply the effect of electromigration by itself, neglecting, at the moment, the other (very important!!) effects we were looking for: Paschen/DBD; Richardson with related Child-Langmuir NOT under usual high vacuum but even at 10-50 mbar of pressure. At such intermediate pressures there is some coexistence with Paschen curve, scientifically interesting but at the moment out of our control.**

- **The in-deep analysis started because in the old times (1994-1998), when we used ONLY pulsed electromigration (we were working in electrolytic environment at about 1 bar of pressure, Pd-Ni or Pd-Pt electrodes), we observed some AHE in specific operating conditions of: electrolytic conducibility, pulse duration, repetition-rate, power injected.**

- **In the recent test some of the operating conditions are even more "intense" in comparison with old, Pd based, material, so the probability to observe something "strange/useful" are increased.**

- **In Fig. 7 are shown typical value of Voltage, Current, Power applied in experiments at high mean power (>90 W). Voltage, (100 V/div., in red), Current (2 A/div., in blue) Power (800 V*A/div., in green) applied to the Cathode, time scale 1 μs/div. Gas pressure, mixture Ar/H_2 (84/16): about 4 bar at RT, 5.2 bar at HT. Wire temperature about 580 °C.**

- **Fig. 8 is similar to Fig. 7 for operating conditions. It is shown the High Voltage (in red, 200 V/div) applied to the anode, maximum value about +1060 V. As reference, it is used the current (in blue) but with time scale of 2 μs/div, to can observe some evolution of peak voltage versus time. The reference value of voltage didn't start from 0 V but from a higher value (about +400 V): *applied to get pre-ionization of the gas mixture (see Paschen curve, Fig. 5)* in the case of, future, proper gas pressure reduction.**

- **Fig. 9, Fig 10. Studies of the effect of AHE changing the input mean power: a) by variation of repetition rate (1, 1.5, 2.0, 2.5 kHz); b) peak power of each pulse (from 64 up to 4640 W). It is apparent the beneficial effect of higher temperatures. Gas composition was kept constant: pure H_2 at 5 bars. Reference is the same wire in DC conditions.**

- **Fig. 11, at the end, shows the unexpected beneficial effect of HPPP (High Peak Power Pulse, as labelled in our publications since 1994 experiments) for enough long time of pulsing: it was able to *activate* the wire, i.e. *make it allowable for AHE generation in DC, even after some days from the end of pulsing.***

- **To prove such beneficial effect were made specific test changing gas mixture composition ($H_2 \rightarrow H_2$/Ar 60/40$\rightarrow H_2$/Ar 16/84) and, at the end (i.e. H_2Ar 16/84), even "deloading", as much as possible, the wire from the Hydrogen stored in the bulk.**

- **Restoring of initial "good conditions", at the moment, was only partially achieved. We just guess that, in the deloading procedures (mainly by vacuum at high temperatures and long times) happened several sintering at the surfaces of the submicrometric, useful, "active" location that are the main places where AHE could happen. Active side model (but with different explanations) was pointed out, among others, by Edmund Storms and Mitchell Swartz, both in USA.**

- **In our project, one of the roles of the mixed *plasma* of Ar and H_2, i.e. Paschen/DBD regimes, was to "reactivate" surfaces that went not active anymore because, spontaneous, several "aging effects".**

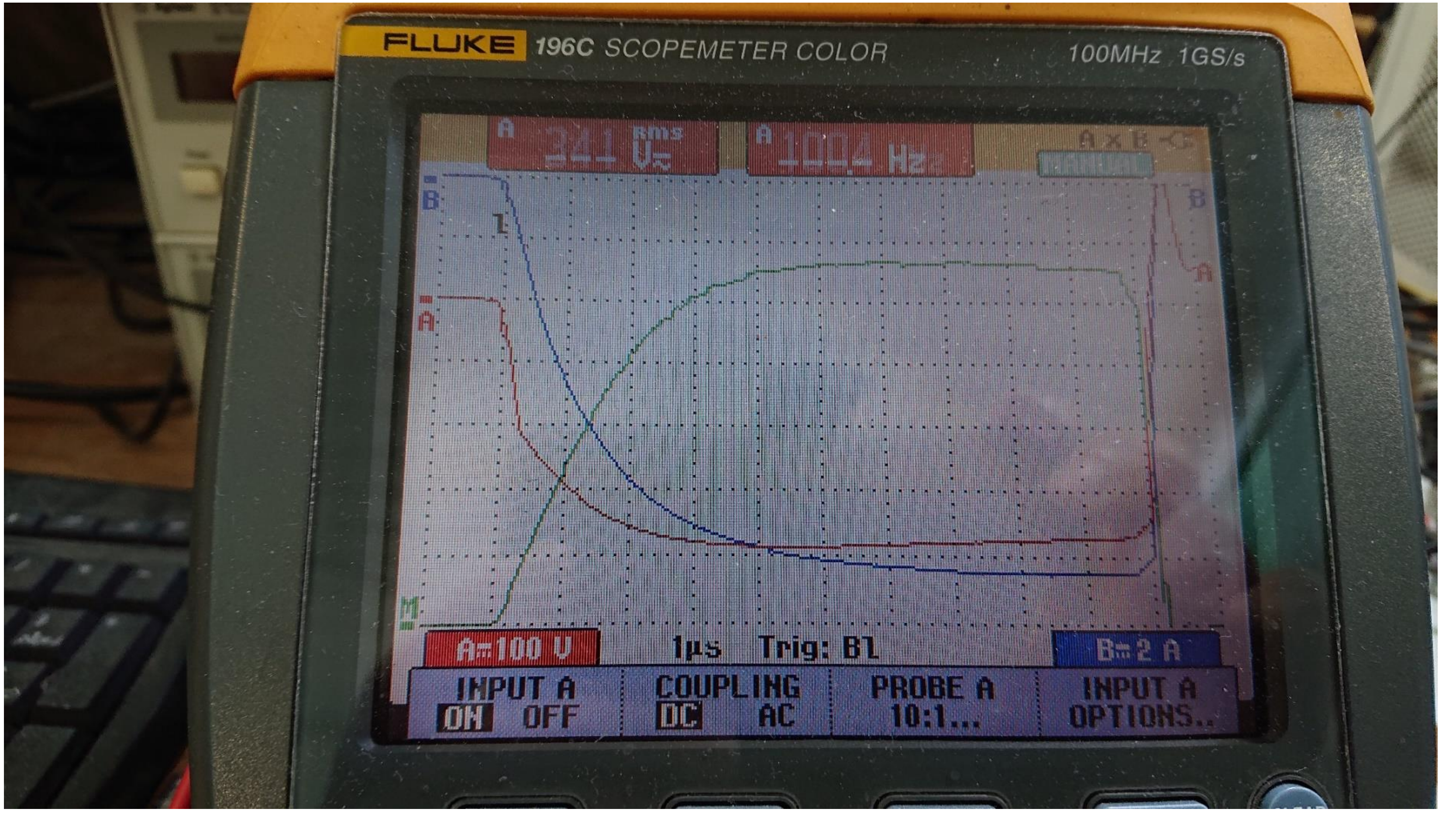

Fig. 7. Snapshot of Voltage (red colour, 100 V/div, maximum value -380 V)), Current (blue colour, 2 A/div, maximum value -12.4 A), Power (scale factor 4, 800 W/div, maximum value 4500 W) of a typical high-power pulse. Time scale is 1 μs/div. The repetition rate was the highest up to now used (2.5 kHz).

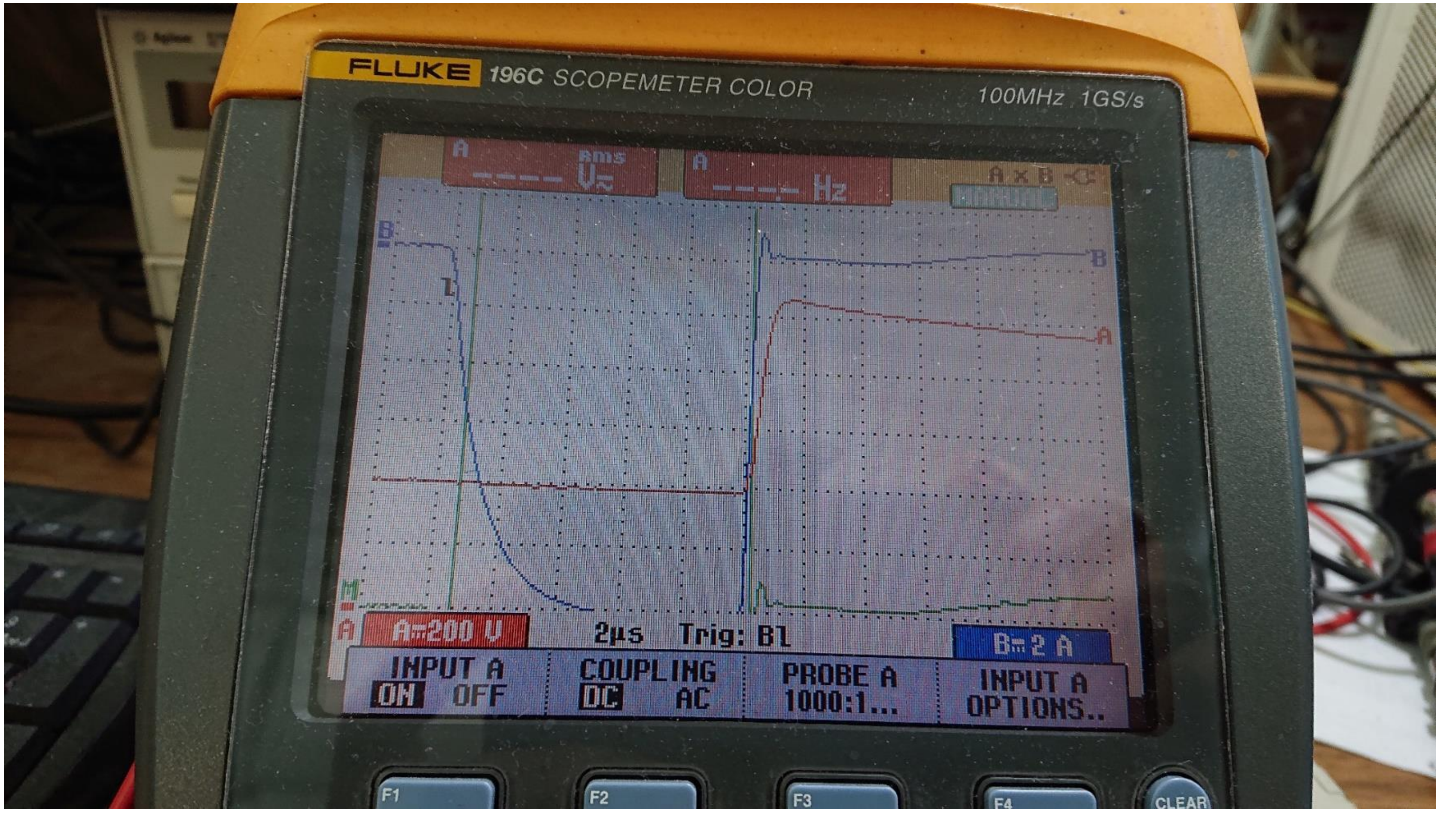

Fig. 8. Snapshot of the peak voltage at the counter electrode (red colour, 200 V/div, maximum value +1060 V). Shown also, as reference, the current applied (blue colour, 2 A/div). The large positive voltage is due to the "opening circuit phase" of the pulse. It is extremely fast because combined effects of both overall electronic arrangements and intrinsic fall time performance of SiC switch used at our operating point (<<100 ns).

Main results

Main details reported under the figures, as shown on Fig. 9, Fig. 10, Fig. 11.

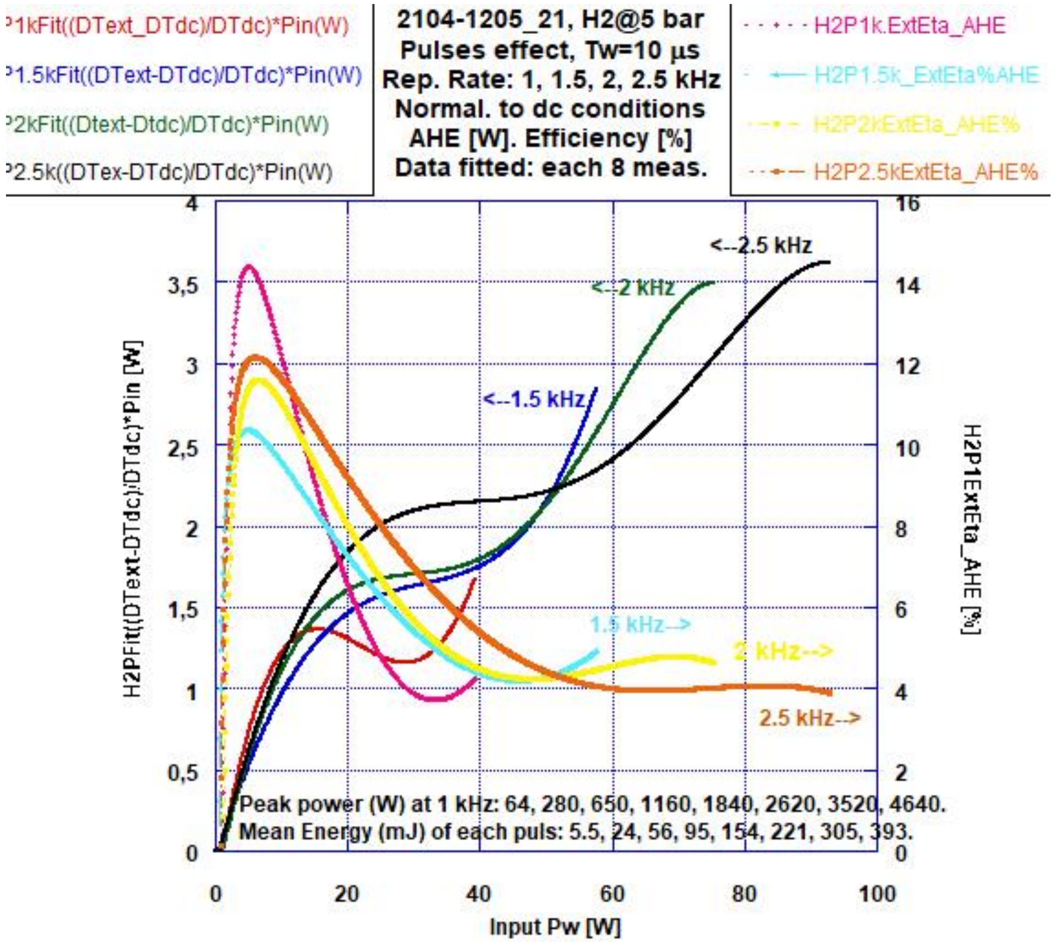

Fig. 9. Only Electromigration effect; H_2 at 100%, 5 bars. Plot of % of AHE changing the peak power pulses (explored 8 values, 64→4640 W, detailed at the foot of figure) and repetition rate (4 values:1, 1.5, 2, 2.5 kHz). Data normalised, at the same input power in DC conditions. Shown both external temperature (left) and internal (right). At low mean power the AHE% is larger at internal side in respect to external. At higher powers they tend to be similar (about 4%).

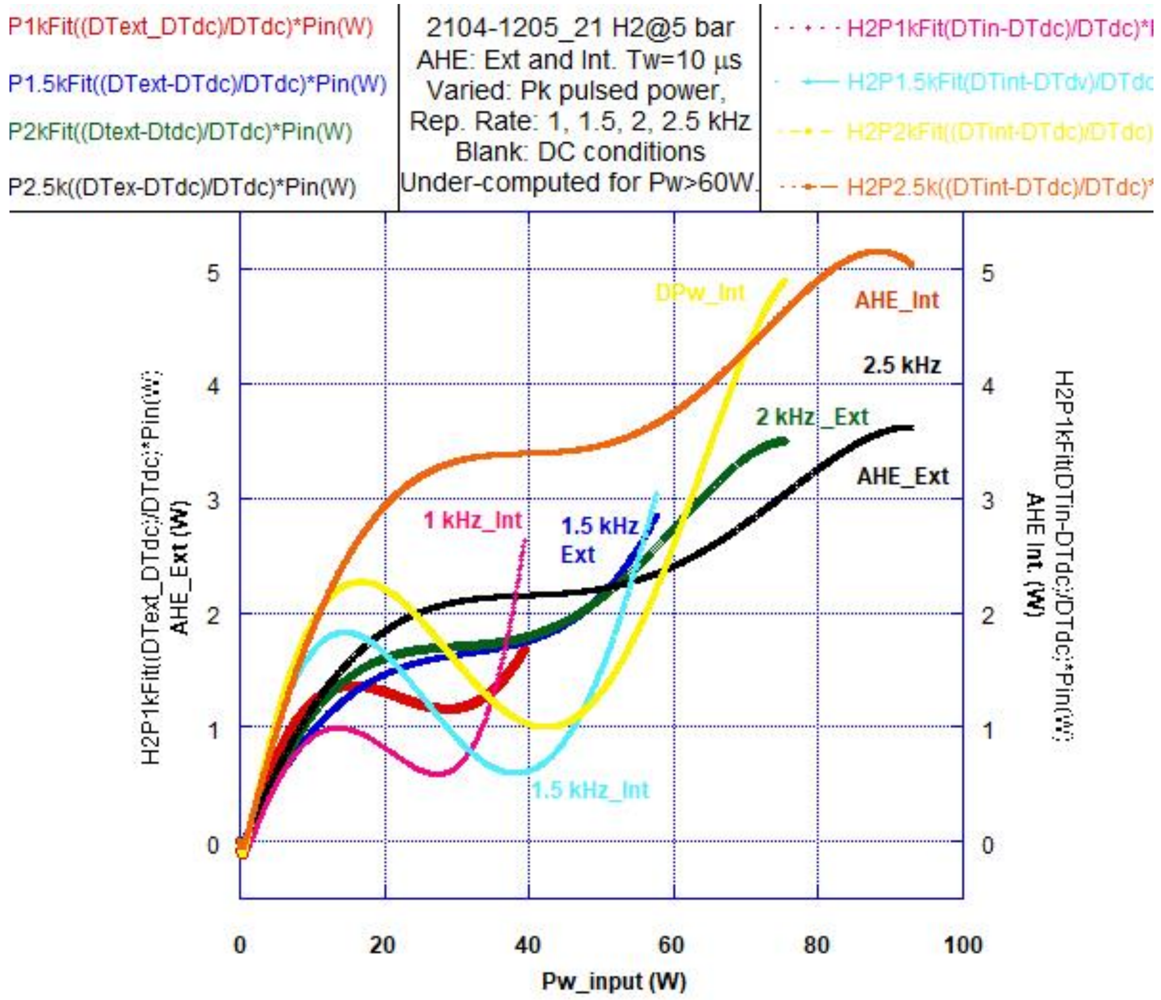

Fig. 10. Only Electromigration effect; H_2 at 100%, 5 bars. Plot of absolute AHE. The values increase, increasing the power applied, i.e. the temperature. Further test needed to explore absolute temperature effects by themselves. As usual, the blank is made by similar experiments, same gas and pressure, in DC conditions.

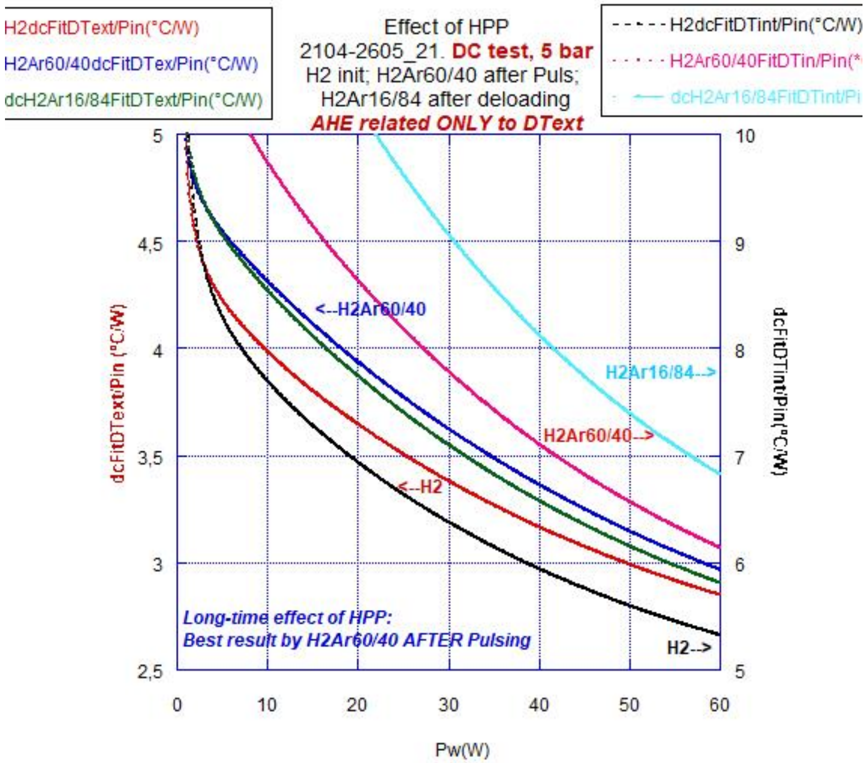

Fig.11. Unexpected, useful effect after HPPP treatments: applied over $2*10^7$ pulses at 10 kV*A/g. Shown the ratio of DT/W (external, left side; internal, right side) versus input power. 1st test with H_2 only in DC conditions (reference, black and red colour). 2nd test after pulses on H_2 (R/Ro decreased from 1 to about 0.80) and changing the gas composition to H_2/Ar=60/40. Increased both external (blue colour) and internal (pink colour) temperatures, last expected because lower thermal conductivity of Ar. 3rd test: before "deloaded" the wire of H_2 previously adsorbed (R/Ro went back to 0.97); then changed the gas composition to H_2/Ar=16/84. Results: internal temperature (light blue) increased largely, gas effect as expected; the **external temperature** (green curve) **DECREASED** in respect to 60/40 composition. It is a clear demonstration of HPPP: they **"activated"** the material.

Conclusions

1) **It was experimentally demonstrated that the "old" beneficial effects of HPPP, by us discovered since 1994 on very costly (recently about 75 €/g) Pd system, *can be "transferred" also to the low cost (about 20 €/kg) Constantan alloy.***

2) **The pulsing procedure, by itself, is able to induce some AHE, stable over time. *The effect seems to behave positive feedback toward the temperature range up to now explored (maximum 600 °C). We expect further advantages at temperatures over 700 °C, where the Richardson regime is of some intensity.***

3) **Moreover, we have found, just by chance, a procedure to "*activate"* our specific Constant wires and make them allowable for AHE production, if other side conditions (proper gas, high temperature, sponge surface covered by LWF materials, thermal gradients,…) are fulfilled.**

4) The activation was found enough stable to be beneficial also in dc conditions, even after some days from the ending of the pulsing.

5) From a theoretical point of view, one of the most realistic hypothesis on the origin of anomalous heat is based on the active role of Nickel-Copper alloys in the decomposition of molecular hydrogen and in the catalysis of Ultra-Dense Hydrogen (UDH) formation, according to Leif Holmlid's (Univ. Goteborg-SE) models and experiments. In the case of Holmlid the non-equilibrium was applied, mainly, by intense Laser pulses. See also: *Unified Field Theory and Occam's Razor: Simple Answers to Deep Questions*; by A. Kovacs and Collaborators, World Scientific Publishing, July 2021.

6) We hope, in the near future, to overcome the problems of catastrophic coil destruction and can use fully the possibilities given by the combined effects of Richardson, Child-Langmuir, Paschen/DBD, Skin, from the point of view of increasing the values of AHE up to now measured ➔

Toward practical applications of LENR-AHE by

low-cost, low-polluting materials, simple procedures.

Acknowledgements

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 (by their Scientist and Technicians): a fully independent cross-check of our most critical experiments was useful to increase our confidence on reported results. Since 2017 we initiated a multiple collaboration with **NEMC** and **SIGI-Favier** (Italy-France), to design an original hybrid sheath obtained by crossing glass and Alumina–Quartz fibres. The 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[1]. Moreover, the sheaths are porous, holes of micrometric dimension: *one of the key aspects of our experimental set-up.*

Institute **F**luid **A**ssociation, Rome-Italy, provided us, from several years, some economical support about consumable of Laboratory and expenses for trips even abroad Italy because Conferences/Workshop/Meetings.

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

We are glad to Jed Rotwell-USA that, as usual, improved not only the English Language aspects of our presentations but gave us also useful advices.

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 Broadbit Company.

This work has received funding from the European Union’s Horizon2020 Framework Programme, under grant agreement # 951974.

Disclaimer

The work reported is under the fully responsibility of the Authors and didn’t represent necessary the opinion of whole CleanHME International project.

In the framework of LENR-AHE (Anomalous Heat Effects) studies we focused, since 2011, on innovative, low-cost materials instead of the usual, precious-metal, Pd. We found that the Cu-Ni alloy, also used for J-type thermocouple construction, has the peculiarity of easy dissociation of H_2 (or D_2) from molecular to atomic state, at enough low temperatures (150 °C), and to keep it inside the lattice and/or at surfaces, up to temperature of 700-800 °C, even at low gas pressures (few bar). Because long time experience (since 1994) on thin and long wires geometry of the electrodes, we concentrated our efforts taking advantages of such specific shape, specially from the point of view of electromigration of ab/adsorbed H, under proper longitudinal electric field (0.5-1 V/cm), DC and/or pulsed. On 1995 we got noticeable results using Pd wires in electrolytic environments (D_2O) at mild temperatures (40-60 °C). Later-on, in some experiments, we used even gaseous environments at high temperatures (up to 700-800 °C). Main problem of Pd was its large brittleness after H, D absorption.
Moreover, we experimentally reconfirmed that one of key condition to induce AHE is the “flux” of H moving inside its lattice (longitudinal) or through the surface (transversal). Pioneers of transversal flux were G.C. Fralick-NASA; M.K. Kubre-SRII-USA, Y. Iwamura-MHI-J, Y. Arata-Osaka Univ.-J We focused on longitudinal flux (following the theoretical models developed by G. Preparata-Milan Univ.-I), although our unconventional electrolytic experiments (1995-1998) had both.
Anyway, apart the initial state, the flux needs external energy to be continuously activated because, in our experience, AHE are due to non-equilibrium conditions, i.e. are needed continuous stimulations, usually energy consuming, apart some specific (but delicate) geometrical set-up (like Capuchin knot in some of our geometrical arrangements).
Recently we developed an unconventional geometry of the electrode aimed to use, at almost the same time, longitudinal and transversal flux at high temperatures in gaseous environments: our goal is to minimize extra energy added, to maximize the AHE and keep it operative for time as long as possible.
At ICCF22 we presented results obtained using Constantan wire arranged as *reversed coaxial coil* with inner electrode made by Fe tube. The thin Constantan wires had the surface treated to make them at submicrometric dimensionality and covered by a mixture of Low Work Function (LWF) materials.
We observed that the time span of AHE was increased just by activating the wire surface by mild sinusoidal High Voltages (50 Hz, up to +-600 V, few mA), while the coil was DC powered to get both DC electromigration and proper high temperatures (>600 °C). The activation was effective mainly at low gas pressures, where the Richardson regime is possible. The Fe counter electrode operated mainly as electron acceptor, thanks to high voltage (Child-Langmuir effect) and low pressures. Because low pressure, over time, we observed an excessive de-loading of the H from the surface of the Constant, until the AHE vanished. So, to keep the AHE, some proper amount of H_2, i.e. enough large pressure (some hundreds of mbar), is needed. The effect is improved if the gas is ionised, i.e. Paschen/DBD regimes. Considering all such requirements we designed such coiled coil able to operate at high voltage in *pulsed* conditions: we could get, at the same time, very high values of electromigration (pulsed condition), large temperature because longitudinal current, transversal excitation i.e. flux, because gas ionization at mild pressures (high voltage), Richardson regime (for short time) just reducing gas pressure, all properly compatible with peculiar Paschen behaviours.
We will explain the specific set-up and summarise the recent results obtained, also considering the severe stress of the system: High Voltage, High Pulsed Power, High Frequency, High Temperatures.