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# THE FEATURES OF INTENSE ELECTRON FLOW IMPACT ON METAL HYDRIDE ELECTRODE[†]

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The features of generation of a shielding plasma layer by a $Zr_{50}V_{50}$ metal hydride surface which prevents the sample from melting have been studied. The sample was interacting with an electron beam formed directly by the metal hydride. The electron beam was emitted from primary plasma generated by an additional discharge with a filament cathode and accelerated in the space charge layer at the front of the shielding plasma, which is formed on hydrogen desorbed from metal hydride or on the sample material in case of the depletion of stored hydrogen. Three different stages of the formation of shielding plasma layer have been identified depending on the ratio between the current to the metal hydride $I_{MH}$ and the current of the primary plasma source $I_d$. When $I_{MH}/I_d < 1$ the classical conditions for charged particles transfer are realized. At $I_{MH}/I_d > 1$ the classical conditions for the transfer of charged particles are violated and double layer appears at the front of the shielding plasma, which ensures the efficient energy transfer from external electrical field to the energy of bipolar motion of charged particles.
**Keywords:** metal hydride, plasma shielding layer, electron flux
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The application of metal hydrides as protective elements of structural materials for plasma devices has been expressed in [1-2]. Under the material subjection to high thermal and energy loads the formation of a shielding plasma layer protects the surface from an incident plasma flow and prevents its erosion. The most suitable materials for the practical application are getters based on ZrV alloys [3]. These materials are characterized by low equilibrium pressures, high velocities and large thermal effects of sorption-desorption of hydrogen isotopes. Due to the decomposition of hydride phases plasma energy dissipation occurs on a gas-dynamic shielding target, which is formed self-consistently by the surface and prevents from the erosion of plasma facing surface.

The studies on coaxial plasma accelerators RPI and QSPA have shown that a protective layer is formed by the surface for hundreds of nanoseconds with an average density higher than $10^{17}$ cm$^{-3}$ and an electron temperature of 5 eV. The duration of the plasma shielding layer is significantly longer than the time of plasma stream propagation (~ 3 μs). In case of RPI there were no spectral lines of the components of metal hydride matrix from the protective layer [1]. But the shielding effect of course is not absolute. Increasing the energy density of plasma stream from 15 J/cm$^2$ (RPI) to 30 J/cm$^2$ (QSPA) resulted in the surface layer melting and weight losses of the sample [2].

Stationary bombardment by high-energy hydrogen particles (5 keV, 100 mA/cm$^2$) [3] and $Ar^+$ ions (8 keV, 1.5 μA/cm$^2$) [4] was also revealed the sputtering of metal hydride surface. But, the sputtering rate of the metal hydride was nevertheless significantly lower compared to materials that do not form hydride phases.

Thus, the interaction of metal hydride with plasma flows or with flows of positive ions has been carefully studied, whereas interaction with electron fluxes has not yet been considered. The purpose of this work is to study the features of the influence of an electron beam on the generation of shielding plasma and the processes of melting of the sample, which could be promising in case of current disruption in plasma devices.

## EXPERIMENTAL SETUP

The experiments were carried out using a plasma source based on a reflective discharge with a filament cathode mounted to a vacuum chamber (Fig. 1). The source operation was released by the application of the negative potential $U_d$ = -100 V to the filament cathode (anode and the vacuum chamber was grounded) and hydrogen injection from balloon to the region of the filament cathode to the pressure of ~ $2 \cdot 10^{-4}$ Torr. The discharge current was $I_d$ = 1 A. The plasma source was in a longitudinal bell-shaped magnetic field with a maximum intensity of 0.06 T in order to form a diverging stream of primary plasma to the vacuum chamber. It allows to obtain sufficiently dense (~ $10^{10}$ cm$^{-3}$) primary plasma in the chamber at low pressures (~ $10^{-4}$ Torr). The shielding plasma layer *5* was formed around the tungsten holder *6* with metal hydride element *7*, which was under positive potential $+V_{MH}$.

The metal-hydride element was produced from the alloy of $Zr_{50}V_{50}$ by the standard method [5]. It includes an alloy activation and filling with hydrogen. Then crushed hydride was mixed with a copper powder followed by pressing it in a disk 20 mm in diameter with a thickness of 4 mm. The quantity of accumulated hydrogen in produced electrode was measured by Siverts method [5] and was about 800 cm$^3$ under normal conditions.

The decomposition of the hydride phases followed by hydrogen desorption is also accompanied by energy absorption, which limits the temperature of the sample and prevents its melting. At low temperatures of 80 – 350 °C the

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desorption is caused by the decomposition of intermetallic hydrides $ZrV_2H_x$, and further by the destruction of the zirconium hydride in the temperature range of 400 – 650 °C [5].

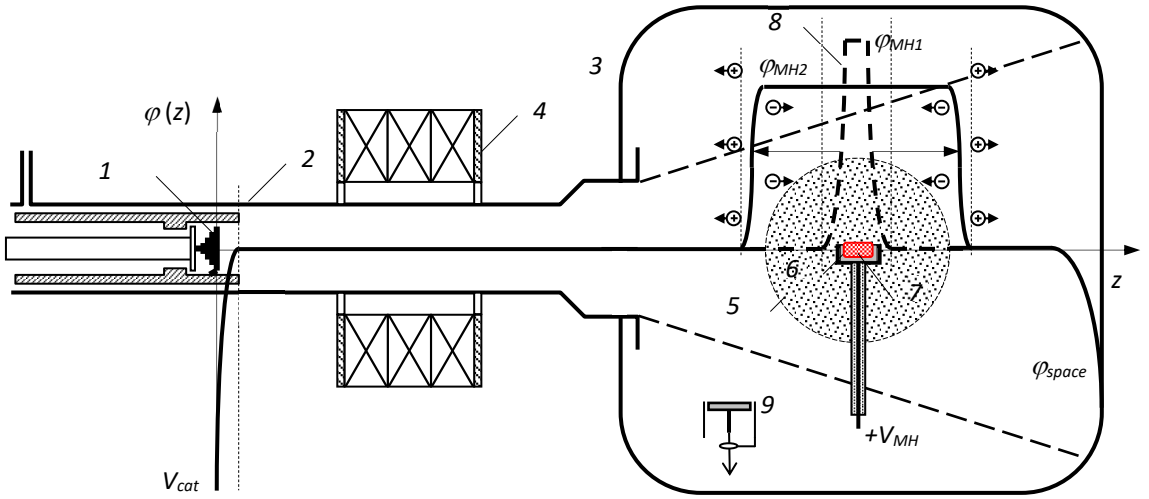


**Figure 1.** The scheme of experiment
1 – filament cathode, 2 – discharge tube, 3 – vacuum chamber, 4 – magnetic field coils, 5 – shielding plasma layer, 6 – tungsten holder, 7 – metal-hydride element, 8 – potential distribution near the metal-hydride, 9 – flat probe

The dynamics of floating plasma potential $\varphi_{space}$ was registered by a flat probe *9*, which was installed in the chamber outside the plasma source stream. Assuming that the voltage $V_{MH}$ is redistributed only between the anode layer and the grounded chamber wall, one can calculate the potential in the layer near the metal hydride element: $\varphi_{MH} = V_{MH} - |\varphi_{space}|$

## RESULTS AND DISCUSSION

The application of positive potential $+V_{MH}$ to the metal hydride element resulted in the formation of a space charge layer with a potential drop $\varphi_{MH1}$ near its surface. In the layer the electrons from primary plasma are accelerated, and an electron beam is formed that heats the metal hydride. As the sample heats up, a flow of neutral atoms of desorbed hydrogen appears. Due to the electron impact ionization the part of loaded energy from the primary plasma is spent on the ionization and excitation of neutral hydrogen. The more power is loaded in, the greater hydrogen amount is desorbed and the denser shielding plasma is formed by the surface.

At low power of ~ 20 W ($I_{MH} \approx 0.1$ A, $V_{MH} = 200$ V) supplied to the metal hydride the pressure in the chamber increased from $2\times10^{-4}$ Torr to $6\times10^{-4}$ Torr after about 30 seconds of continuous exposure and the shielding plasma layer with potential $\varphi_{MH1}$ was formed (1st stage). All the positive voltage applied to the metal hydride $V_{MH}$ is concentrated in the layer near the surface $\varphi_{MH1}$, the space potential has a small negative potential ($\varphi_{space} \sim T_e/e$) and the dependence of $V_{MH}$ on $\varphi_{MH1}$ is linear (Fig. 2*a* green line).

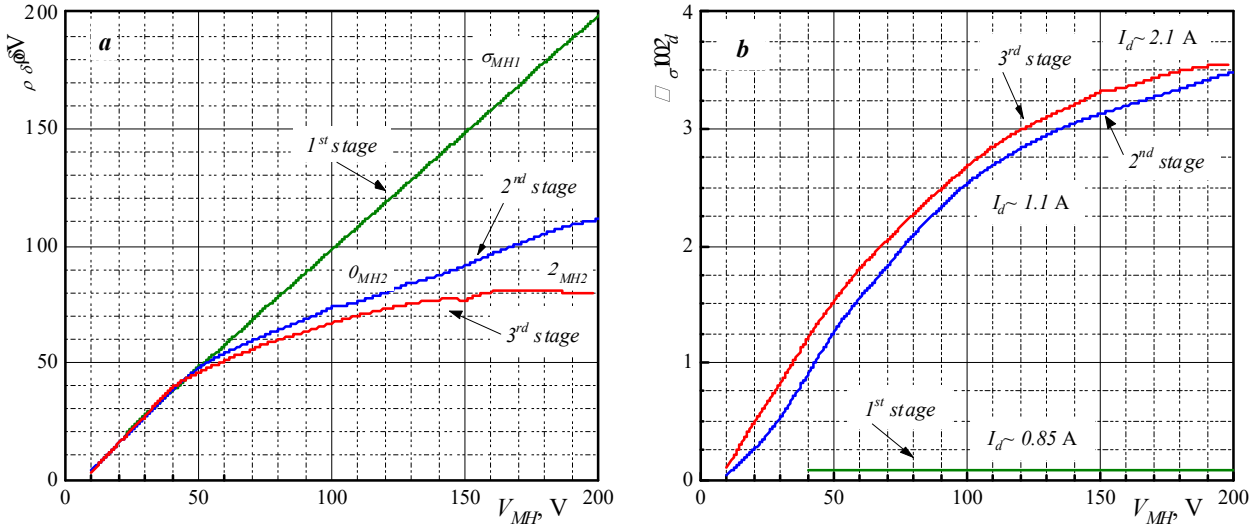


**Figure 2.** The dependence of potential $\varphi_{MH}$ in the layer near the metal hydride element (*a*) and ratio of the metal hydride current to discharge current $I_{MH}/I_d$ (*b*) on the voltage applied to the metal hydride element $V_{MH}$

The current to the metal hydride $I_{MH}$ is less than the discharge current of the primary plasma source $I_d \sim 0.85$ A and doesn't depend on the voltage applied to the metal hydride $V_{MH}$ (Fig.2*b* green line).

A further increase of the power supplied to the metal hydride element to 60 W ($V_{MH}$ = 600 V at a constant current $I_{MH} \approx 0.1$ A) leads to a significant increase of hydrogen desorption rate (the pressure raised to $5\times10^{-3}$ Torr) and the current to the metal hydride drastically jumps (2nd stage).

In this stage dense ($n > 10^{10}$ cm$^{-3}$) shielding hydrogen plasma forms around the metal hydride, immersed in lower density primary plasma (Fig. 1). Starting from $I_{MH}/I_d = 1$, the classical conditions for the charged particles transfer are violated, because there are no longer enough ions generated in the primary plasma to cover the excess current on the metal hydride. The initial surface layer $\varphi_{MH1}$ turns into double electric layer (DL) $\varphi_{MH2}$ at the front of the shielding plasma, where the intense electron and ion beams are accelerated in the opposite directions [6].

An increase in the slope of the *blue* curve (Fig.2*a*) indicates on a redistribution of applied to metal hydride voltage $V_{MH}$ between the DL potential $\varphi_{MH2}$ and the $\varphi_{space}$ potential.

Appearing of the positive potential near the wall rises the current to the metal hydride. The chamber wall plays the role of the cathode of a non-self-sustaining glow discharge, providing additional generation of charged particles in the chamber. The metal hydride plays the role of an anode.

Spending the energy loaded from primary plasma on the ionization and excitation of neutral hydrogen released from metal hydride causes the shielding properties of the plasma formed around the sample. The decomposition of hydride phases followed by hydrogen desorbtion is also accompanied by energy absorption, which limits the temperature of the sample and prevents its melting.

When all stored hydrogen is desorbed from metal hydride the shielding plasma conditionally transits to the 3rd stage (red curves in Fig. 2). The physical processes here develop according to a similar scenario but more intense. The shielding plasma layer is formed on the sample material, but not on the desorbed hydrogen. For process stability of shielding plasma formation, we had to increase the discharge current of the primary plasma source to $I_d \sim 2.1$ A.

There are no longer any limiting factors for increasing the sample temperature, and when supplied power is about 60 W ($I_{MH} \approx 0.1$ A, $V_{MH} \approx 600$ V) the melting process of the sample begins after about 30 second. Fig. 3 shows the photo of metal hydride surface after the impact of electron flow. Fig. 3*a* corresponds to the case of shielding plasma formation under hydrogen release from metal hydride, Fig. 3*b* – to the case of hydrogen depletion in metal hydride.

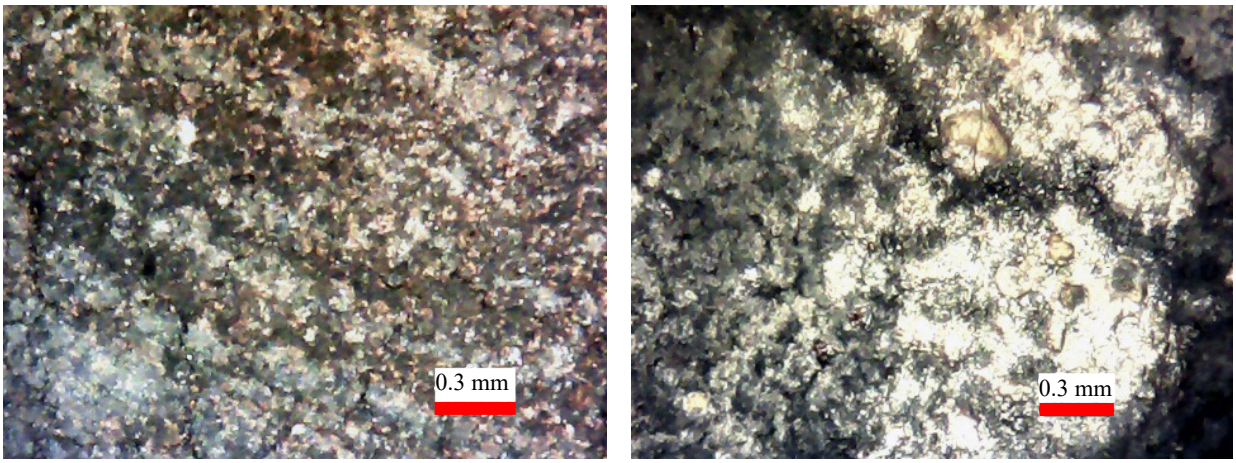


**Figure 3.** The photo of metal hydride surface after the impact of electron flow
a – the case of hydrogen release from metal hydride; b – the case of hydrogen depletion in metal hydride.

The DL formation at the front of the shielding plasma in case of hydrogen depletion is the most dangerous, because of addition damage of the sample material (Fig. 3*b*), deposition on the ambient surfaces and hydrogen plasma contamination.

## CONCLUSION

Thus, we can assume the following scenario for the interaction of intense electron flow with the metal hydride. A shielding plasma layer is formed on hydrogen released from metal hydride, which shields the surface from extreme heat and energy loads.

When the current to metal hydride is less than the current of plasma source ($I_{MH}/I_d < 1$), the applied voltage $V_{MH}$ is concentrated in the layer near its surface $\varphi_{MH1}$, and the wall has only a small ($\varphi_{space} \sim T_e/e$) negative potential.

If the current to metal hydride exceeds the current of primary plasma source ($I_{MH}/I_d > 1$), the classical conditions for the transfer of charged particles are violated and double layer (DL) appears at the front of the shielding plasma. Due to the redistribution of applied $V_{MH}$ voltage between DL ($\varphi_{MH2}$) and near-wall layer it adjusts the current to metal hydride and ensures the efficient energy transfer from external electrical field to the energy of bipolar motion of charged particles.

Due to the energy absorption by hydride phases decomposition the formation of shielding plasma on released hydrogen occurs at limited temperatures which is significantly lower than the melting temperature of the sample. This makes the application of metal hydrides attractive as the materials of plasma facing elements.

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**ОСОБЛИВОСТІ ВЗАЄМОДІЇ ІНТЕНСИВНОГО ПОТОКУ ЕЛЕКТРОНІВ З МЕТАЛОГІДРИДНИМ ЕЛЕКТРОДОМ**

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Досліджено особливості формування захисного плазмового шару біля поверхні металогідриду $Zr_{50}V_{50}$, що перешкоджає плавленню зразка. Зразок взаємодіяв з електронним пучком, що формується безпосередньо біля гідриду металу. Електронний пучок вилучався з первинної плазми, що генерується додатковим розрядом з катодом, що розжарюється, і прискорювався в шарі об'ємного заряду на фронті екрануючої плазми, що утворюється на водні, який десорбується з металогідриду, або на матеріалі зразка, у разі виснаження запасів водню. Виявлено три різні етапи формування екрануючого плазмового шару залежно від співвідношення струму на гідрид металу $I_{MH}$ та струму первинного джерела плазми $I_d$. Коли $I_{MH}/I_d < 1$ реалізовано класичні умови перенесення заряджених частинок. При $I_{MH}/I_d > 1$ порушуються класичні умови перенесення заряджених частинок і на фронті екрануючої плазми виникає подвійний шар, що забезпечує ефективний переіс енергії від зовнішнього електричного поля до енергії біполярного руху заряджених частинок.

**Ключові слова:** гідрид металу, плазмовий екрануючий шар, потік електронів