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INFLUENCE OF SATURATION DEGREE OF METAL-HYDRIDE CATHODE ON CHARACTERISTICS OF PENNING TYPE ION SOURCE OF HYDROGEN

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The experimental examinations of Penning type plasma source of hydrogen ions using metal-hydride cathode was carried out. The discharge characteristics, radial distributions of plasma parameters were measured in a gap between the anode and the metal-hydride cathode for different degree of hydrogen saturation of the cathode material. The plasma parameters and voltage drop on the discharge was shown to be depended on the degree of saturation with hydrogen of the metal-hydride cathode. Plasma density on the axis of the system was established to be increased in accordance to the increase of the initial hydrogen saturation of the metal-hydride cathode. This phenomenon is explained by the increase of a desorption intensity of hydrogen from the central part of the surface of the metal-hydride cathode.

1. INTRODUCTION

The analysis of existing opportunities of utilization of metal-hydrides in systems of gas feeding of hydrogen isotopes of vacuum-plasma devices has shown that the combination of hydrogen-sorptive and thermalphysics properties of hydrides (reversible getters of hydrogen) allows us to realize the fundamentally new schemes of adjustable "interior" filling of the plasma-generating gas [1]. According to this scheme the metal-hydride source of hydrogen on the basis of hydrogen saturated getter material is used as constructive units of devices-consumers. Such schemes have a number of advantages in comparison with traditional systems of gas feeding. In this case the immediate interaction of the metal-hydride surface with the hydrogen plasma is realized, which improves technical characteristics of a metal-hydride source of hydrogen and a vacuum-plasma device as a whole [2]. However, the mechanism of the interaction of the reversible hydrogen sorbents with the plasma of the gas discharge has not been investigated thoroughly. There are no data concerning the influence of the degree of hydrogen saturation of such materials on the parameters of the discharges using metal-hydride electrodes and on the characteristics of the plasma of ion sources, which was created on this basis.

The purpose of this work is the examination of the influence of the degree of hydrogen saturation of a hydride-forming material on the basis of $Zr_{50}V_{50}$ alloy on the discharge characteristics and on the emissive properties of Penning type plasma ion sources.

2. EXPERIMENT

The experiments were carried out on an installation that is shown schematically in a fig. 1. The installation includes a gas-discharge chamber (1), a system of making an exterior magnetic field (2), diagnostic equipment, a system of a discharge supply (3), a monitoring system of pressure (4), a system of working gas feeding (5) and a system of a vacuum pumping-out (6). The electrodes of the reflective discharge were located inside the quartz cylinder. The anode (7) of the

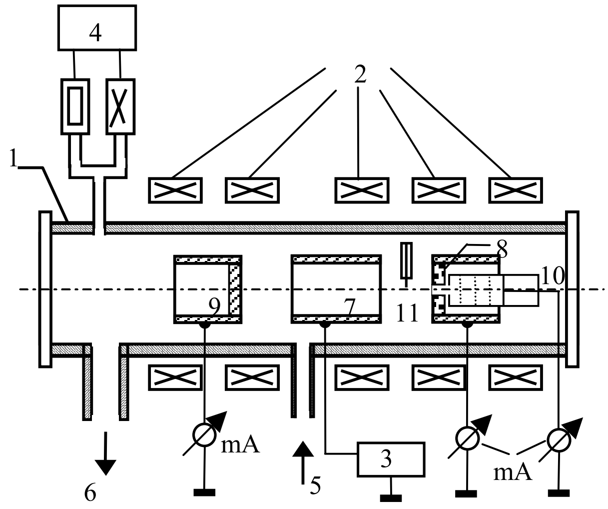

Fig.1. The scheme of experimental device for examination of the reflective discharge using metal-hydride cathode

gas-discharge system was made from stainless steel and represented the hollow cylinder 3,2 cm in diameter and 3,0 cm in length. The metal-hydride cathode (8) was performed in a form of a disk electrode with a diameter of 20 mm and a width of 4 mm from $Zr_{50}V_{50}$ getter alloy saturated with hydrogen. It was pressed with copper binding powder. The content of a copper filer formed 40 % from the mass of hydride. The maximum amount of the accumulated hydrogen in such electrode was 2,5 dm^3 at standard conditions. In our experiments metal-hydride cathodes were used with the maximum initial degree of hydrogen saturation (the concentration of hydrogen in hydride corresponded to an atomic rating «hydrogen/metal» like H/M = 1,4), as well as with 50 % initial degree of hydrogen saturation (H/M = 0,7). The second cathode (9) was made from stainless steel. In verifying experiments two cathodes from stainless steel were used. The total length of a Penning cell was 7 cm. The residual pressure in a vacuum chamber did not exceed $3\cdot10^{-6}$ torr. The range of changes of an exterior magnetic field was from 0,05 up to 0,1 Tl, and voltage drop on the discharge was from 1 up to 3,5 kV during the experiments. Hydrogen was used as plasma-forming gas which moved from metal-hydride unit of exterior feeding. Using of metal-hydride unit provided high purity (not worse than 99,99 %) of filling hydrogen. The working pressure of hydrogen in a vacuum chamber varied from $5\cdot10^{-5}$ torr up to 10^{-4} torr.

The radial profiles of plasma parameters were measured by Lengmuir probes (11). The probes were settled in the same plane in the middle of the gap between the anode and the metal-hydride cathode. They also were located in different distances from an axial axis of the discharge cell. The energy distributions of ions were investigated by a multigrid energy analyzer (10). The energy analyzer was located in the distance of 5 mm behind a hole in the centre of the cathode (8) (fig. 1). The diameter of the hole in the cathode was 3 mm. The aperture of the energy analyzer was selected in such a way that the collector excepted only those ions that had a ratio of $v_{||}/v_{\perp} >> 1$ between longitudinal and cross velocities.

3. RESULTS AND DISCUSSION

3.1 HYDROGEN-SORPTIVE CHARACTERISTICS OF A HYDRIDE-FORMING ALLOY

The saturation with hydrogen and measurement of getter capacity of the hydride-forming alloy $Zr_{50}V_{50}$ was carried out according to the method of Siverts [3]. The specific saturation of such reversible sorbent of hydrogen was from 210 up to 235 cm^3 per 1 gram of initial alloy at standard conditions. It corresponds to the stochiometric composition of a hydride (ZrH_2+ZrV_2H_x) where the x=3,34 – 4,12 with an atomic ratio H/M = 1,34 – 1,50. The dynamics of the given metal-hydride decomposition was explored using a method of thermal desorption spectroscopy [4]. The measuring of the dependence between the velocity of hydrogen desorption in a pumped out vacuum chamber on the temperature of a metal-hydride sample was carried out under the linear law of the temperature increase dependant on time (fig.2). In the given figure the spectra of the thermal desorption of hydrogen from hydrogenated sample of the alloy are given at different degrees of their saturation, which corresponded to initial values H/M = 1.4 (100 % saturation) and H/M = 0,7 (50 % saturation). The desorption of hydrogen of a completely saturated sample is seen to be carried out immediately turning on the pumping-out. It loses about 0,3 H/M (45 – 50 cm^3 per 1 gram of hydrogen at standard conditions). The thermal desorption of hydrogen in the range from a room temperature up to 400 ^{0}C flows practically with a steady speed with a broad peak of gassing in the field of 200^0 C. The further growth of the temperature results in the increase of the intensity of gassing with the obviously pronounced peak at T=586^0 C. The obtained results are qualitatively agreed with the data of the operations [4, 5]. The first stage of the gassing the authors explain by decomposition of intermetallic hydride ZrV_2H_x, and the second one they explain by decomposition of a hydride of zirconium. For a sample with a degree of saturation H/M = 0,7 (stochiometric composition ZrH_2+$ZrV_2H_{0,60}$) the intensity of desorption of hydrogen from an intermetallic phase is inappreciable and the main part of hydrogen is evolved from a phase of ZrH_2 in the range of temperature from 400^0 C up to 650^0 C.

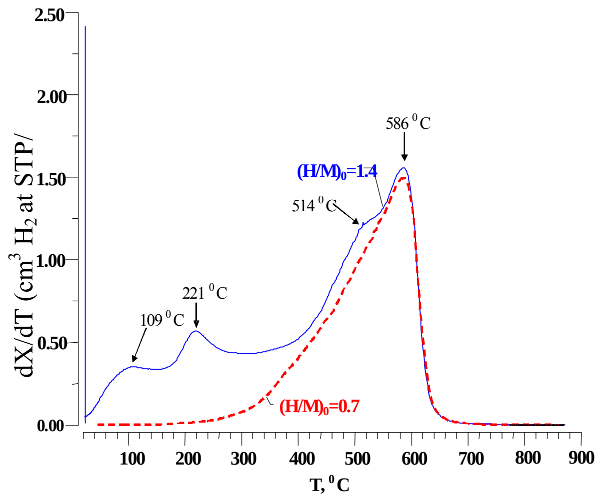

Fig.2. The thermal desorption spectrum of hydrogen from ZrV_2H_x samples with various initial concentrations of hydrogen

3.2. CURRENT-VOLTAGE CHARACTERISTICS AND PARAMETERS OF PLASMA OF THE REFLECTIVE DISCHARGE USING METAL-HYDRIDE CATHODE

Typical current-voltage characteristics of the reflective discharge using metal-hydride cathode are given in fig.3. One can see in the figure at identical exterior parameters the heightened voltage drop on the discharge using metal-hydride cathode is observed. While hydrogen generates from the metal-hydride electrode, the drop of voltage on the discharge diminishes and tends to the typical value for cathodes which is made from materials that do not form hydrides

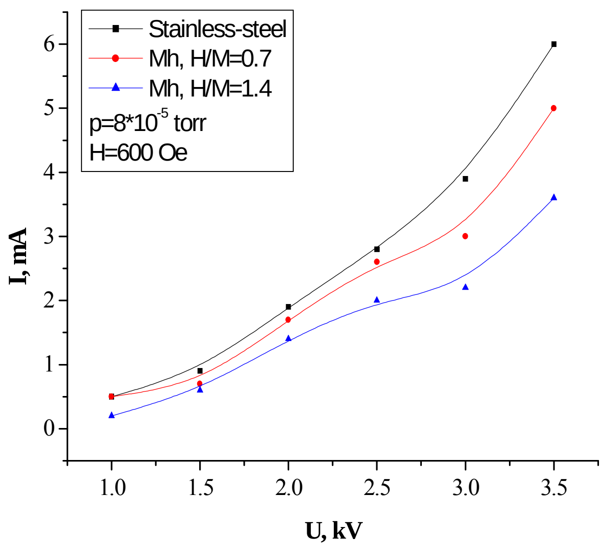

Fig. 3 The current-voltage characteristics of the reflective discharge

(in our experiments the cathode made from stainless steel was used). The obtained result is agreed with the data of the operation [6]. The authors explain this effect by dissociative attachment of low-energy electrons to hydrogen molecules, which is desorbed from the surface of metal-hydride in vibrationally excited state. As a result of this process the negative ion formation of hydrogen H^- near the cathode of the discharge takes place. It leads to the reduction of the electron concentration and prevents from the propagation of the electron avalanches. Consequently in order to maintain the discharge the higher voltage drop is necessary. While hydrogen generates from the metal-hydride cathode the intensity of desorption of vibrationally-exited molecules of hydrogen is reduced. As the consequence of this the contribution of the process of dissociative attachment into losing of electrons near the cathode of the discharge decreases. It is the reason for the rise of the electron concentration and diminution of voltage drop on the discharge.

The increase of working gas pressure leads to approaching of the current-voltage characteristics of the discharge using metal-hydride cathodes with different initial degrees of saturation. In this case collision rate increases and the mean-lifetime of negative ions in the discharge diminishes [7]. Besides it also results in reduction of lifetime of vibrationally excited state of desorbed hydrogen molecules and decrease of capture frequency of low-energy electrons near the cathode of the discharge. Therefore it is observed a voltage reduction on the discharge while the hydrogen pressure increases in the gas-discharge cell even in case of complete initial hydrogen saturation of the cathode (H/M=1,4).

The typical radial distributions of plasma densities, which were measured for different values of initial hydrogen saturation of cathodes, are represented in fig. 4. It can be seen that comparing these dependencies the considerable increase of the plasma density on the discharge axis is observed in case of the cathode with the maximum of initial degree of hydrogen saturation

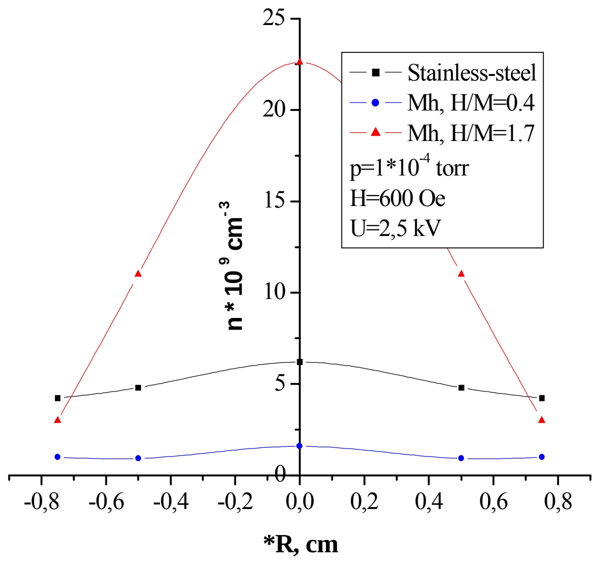

Fig.4. The radial distribution of plasma density in the reflective discharge

(H/M=1,4). While concentration of hydrogen in the metal-hydride cathode decreases the plasma density on the discharge axis reduces and the shape of a distribution curve approaches to the radial distribution, which is typical for the discharge with the cathode that is made from materials that do not form hydrides.

It is possible to explain obtained feature of plasma density distribution in the discharge using metal-hydride cathode by character of current density distribution of ions bombarding the cathode. The radial distribution of current density of ions falling into cathodes of reflective discharge is well known to have the pronounced maximum on an axis of the system. Taking into consideration the conditions of our experiments the hydrogen desorption from the metal-hydride is caused by ion bombardment, the greatest intensity of desorption will be observed from central area of the surface of the metal-hydride cathode. As a result the stream of the hydrogen having major density in paraxial area of the discharge is formed. While hydrogen generates from metal-hydride, the intensity of paraxial stream of hydrogen is reduced, and the radial distribution of plasma density approaches to the shape typical for materials that do not form hydrides. As the material of the cathode is a reversible getter of hydrogen the partly saturated electrode under ions bombardment of its surface will sorb hydrogen as well. It may be presumed to explain inappreciable reducing of plasma density for partially saturated metal-hydride cathode (H/M=0,7) in comparison with the cathode from materials that do not form hydrides (fig. 4).

For the purpose of ascertaining this assumption the measurements of energies distribution of hydrogen ions bombarding the central area of the metal-hydride cathode (fig. 5) were carried out. As one can see from the dependencies that have been demonstrated the degree of initial saturation influences the most probable energy of paraxial group of ions falling into the metal-

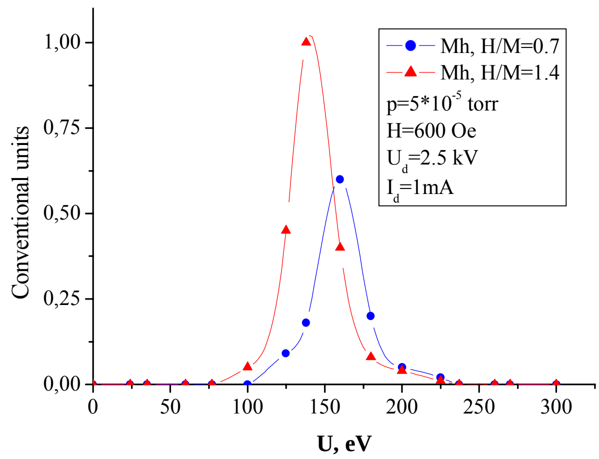

Fig.5. The energy distribution of the paraxial ion group in the reflective discharge

hydride cathode. The reduction of initial hydrogen saturation of metal-hydride leads to the increase of the most probable energy of ions and to diminution of a maximum of energy distribution curve of ions falling into the collector of an energy analyzer. Such behavior of energy distribution of ions is caused by the following reasons. In our experiments the aperture of the energy analyzer was chosen in such a way that only those ions that moved almost in parallel with the axes of the system fell on the collector. The collisions of paraxial group of ions with molecules of hydrogen stream desorbed from the cathode lead to the loss of ion energy. Therefore leftward bias (fig. 5) of a maximum of energy distribution of ions is observed while initial hydrogen saturation of the metal-hydride cathode increases. On the other hand, the rise of the plasma density on a discharge axis caused by a paraxial stream of the desorbed hydrogen leads to the increase of ion current falling into a collector of an energy analyzer as well. As a result the observed character of changes in the energy distribution of paraxial group of ions of plasma is determined by the stream of hydrogen that is desorbed from the metal-hydride cathode.

4. CONCLUSION

The experimental examination of the influence of a degree of hydrogen saturation of a hydride-forming getter material on the basis of $Zr_{50}V_{50}$ alloy on the discharge performances and parameters of plasma of the reflective discharge are carried out. The use of the metal-hydride cathode is shown to be led to the essential change of both exterior parameters of the discharge and parameters of plasma. The dependencies of plasma density and energy distribution of ions in paraxial field of the discharge on a degree of hydrogen saturation of the metal-hydride cathode are investigated. The dependencies of plasma parameters of the discharge on a degree of hydrogen saturation of the metal-hydride cathode is established to be determined by the paraxial stream of hydrogen that is desorbed from the surface of this electrode under ion bombardment.

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