ACTIVATED HYDROGEN INFLUENCE ON CHARACTERISTICS OF PENNING DISCHARGE WITH HOLLOW CATHODE

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The results of experimental investigations of reflective discharge using sectioned hollow cathode are presented. As constructive elements of the hollow cathode an alloy $Zr_{50}V_{50}H_x$ able to absorb hydrogen reversibly under low pressure was used. It has been shown that in case of applying of metal-hydride hollow cathode the penetration of plasma in the hollow occurs sufficiently deeper. The possibility to operate the plasma penetration into the hollow cathode by means of potential variation on its sections was investigated. The peculiarities of energy distribution function of extracted ions were carried out.

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1. INTRODUCTION

It is promising to apply solid-state hydrogen generators based on metal-hydride in gas supply systems of hydrogen vacuum plasma devices. Using electrodes from reversible hydrogen sorbents of $ZrVH_x$ system allows for one's turn to provide internal feeding of spectral-pure hydrogen in necessary field of a discharge gap [1]. Equilibrium pressure over these compounds usually not exceed 10 Pa at room temperature. The working temperature of metal-hydride based on Zr-V alloys is in the range of 400…900 K and gassing flows uniformly in the mentioned temperature range. The peculiarity of generated hydrogen is it’s desorbtion in activated state. It is conditioned on vibrationall excitation of H_2 molecules which are formed as a result of atoms H recombination on the surface of such compounds with the following transition into gas phase of discharge in thermodynamic nonequilibrium state [2]. At that the ionization potential of desorbed hydrogen decreases on 0.5 eV and ionization cross-section increases in 1.5 times comparable with common molecular hydrogen filled from a balloon [3]. It is efficient to apply such a compound as the material of a hollow cathode in gas discharges and ion sources. It was shown in [4] that in this case it is needed sufficiently lower voltage for discharge transition into hollow cathode mode. This phenomena is determined by plasma penetration in the cathode hollow.

In this work experimental investigation of peculiarities of plasma penetration into the metal-hydride hollow cathode and forming energy distribution function of extracted ions were carried out.

2. EXPERIMENTAL SETUP

Investigations of the reflecting discharge in hydrogen environment with the sectioned metal-hydride hollow cathode were carried out on the device which scheme is presented on Fig.1 The total length of the cell was 70 mm. The anode (7) was made from stainless steel and represented itself hollow cylinder 32 mm in diameter and 15 mm length. The sectioned hollow cathode was made from five-disk electrodes 5 mm thick and 20 mm in diameter with a hollow in the center 6 mm in diameter. The sections of the hollow cathode were made from getter powder $Zr_{50}V_{50}$ alloy saturated with hydrogen and pressed with copper binder. The initial hydrogen saturation was 230 g/cm^3 of the alloy at standard condition. The electrodes were electrically insulated from each other through the ceramic insertion 1 mm thick.

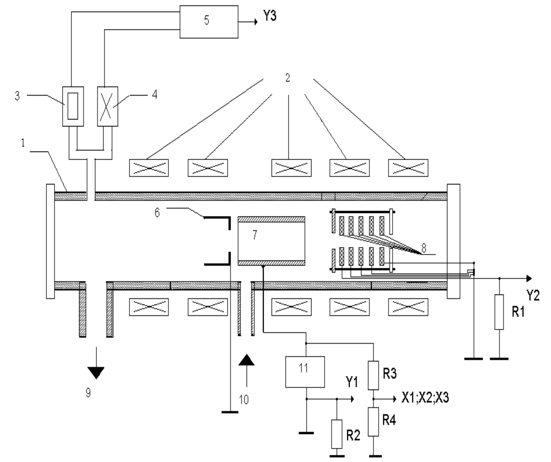

Fig.1. Installation diagram:
1 – vacuum chamber; 2 – magnetic system; 3 – ionizing manometric transformer; 4 – thermocouple manometric transformer; 5 – ionizing - thermocouple vacuum gage; 6 – anticathode; 7 – anode; 8 – set of cathodes; 9 – pumping; 10 – gas supply; 11 – power supply

In the comparative experiments hollow cathode from copper with the same construction and dimension was used. In the center of copper anticathode (6) was a hollow 6 mm in diameter behind which an energy analyzer for energy spectrum investigation of extracted ions was set. The initial working pressure was established at the expense of external hydrogen supply in gas discharge gap or directly through the hollow of the cathode. The change of working pressure was realized at cost of hydrogen desorption from metal-hydride hollow cathode under the influence of ion bombardment. Current on the sections of the hollow cathode and integral distribution function of the extracted ions were measured by two-coordinate self-recording devices PDA-1.

3. RESULTS AND DISCUSSION

Usually in gas discharges with hollow cathode working gas feeding is realized through the cathode hollow to provide the conditions of effective work of such cathode. On the other hand using metal-hydride as cathodes of plasma devices allows to realize internal hydrogen feeding from such material at the expense of its desorbtion under ion bombardment. The comparative investigations of plasma penetration into the hollow were carried out at external hydrogen feeding both into the vacuum chamber and through the hollow of the cathode. On Fig.2 ion current distribution on the sections of the hollow cathode in case of working gas feeding into the vacuum chamber are presented. One can see that at using metal-hydride plasma penetrates into the hollow deeper (Fig.2, curve 3, 4), but currents on the sections of copper hollow cathode are practically in two times bigger (Fig.2, curve 1, 2) in comparison with metal-hydride. Such ion current distribution on the sections of the hollow cathode is explained by following. In case of metal-hydride hollow cathode applying stimulated desorbtion of hydrogen occurs at the expense of the ion bombardment, hydrogen concentration in the hollow locally increases, as a result the conditions of plasma penetration into the hollow deeper are provide. In case of copper hollow cathode it is felt of leak of working gas for effective working of such a device (Fig.2, curve 1, 2). The lower magnitudes of ion current on the sections of metal-hydride hollow cathode at the same discharge current can be explained because of coefficient of secondary ion-electron emission for metal-hydride is lower than for copper and depends on metal-hydride saturation degree [5]. On the other hand, as long as desorbed from such alloys hydrogen is in vibrationally-excited state then in this case the cross section of dissociative attachment of slow secondary electrons emitted from the cathode sufficiently increases [3]. As a result the generation of negative ions takes place that leads to decreasing of electrons able to ionize working gas.

In case of working gas feeding into the hollow the excitation of hollow cathode effect happens at much lower potential magnitudes and plasma penetrates along the whole length of the hollow (Fig.3) as in case of metal-hydride (Fig.3, curve 3, 4)and in case of copper as well (Fig.3, curve 1, 2). It is worth mention that in case of hydrogen feeding directly through the hollow of the cathode the more stable discharge working was observed. Therefore following investigations were carried out in the hydrogen feeding through the hollow mode.

For the purpose of investigation of possibility to operate of plasma penetration into the hollow cathode the discharge behavior at negative and positive potential supplying on its sections was investigated.

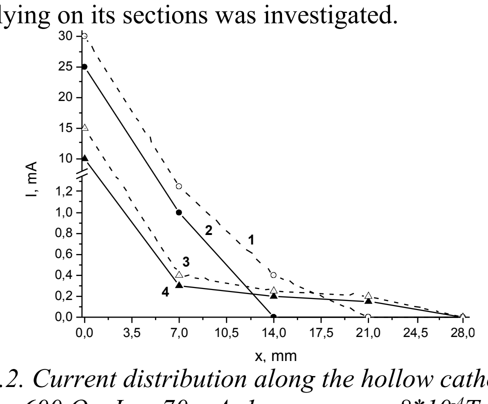

*Fig.2. Current distribution along the hollow cathode. H = 600 Oe, I_d = 70 mA. 1-copper, p = 8*10^{-4}Torr; 2 -copper, p = 6*10^{-4} Torr; 3-metal-hydride, p = 8*10^{-4} Torr; 4-metal-hydride, p = 6*10^{-4} Торр*

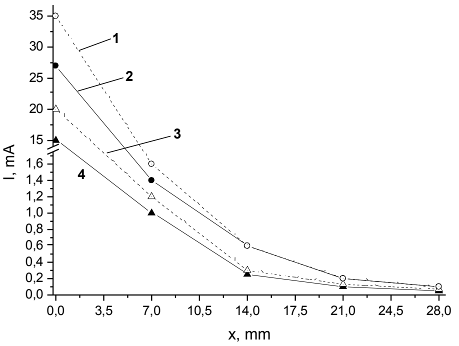

*Fig.3. Current distribution along the cathode under the gas feeding through the hollow. H = 600 Oe, I_d = 70 mA.1-copper, p = 8*10^{-4}Torr; 2-copper, p = 6*10^{-4} Torr; 3-metal-hydride, p = 8*10^{-4} Torr; 4-metal-hydride, p = 6*10^{-4} Торр*

Negative voltage supply on all sections of the hollow cathode led to the shift of excitation potential of hollow cathode to the lower magnitudes. However the transition in hollow cathode mode in case of metal-hydride applying was realized at lower voltage drop [4]. At that the character of current distribution on the cathode sections changes (Fig.4, 5).

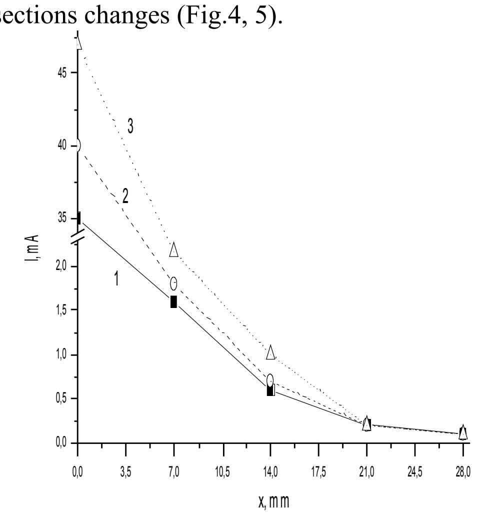

Fig.4. Ion current distribution on the sections of the copper hollow cathode under negative potential supplying on all sections. p = 4·10^{-3} Torr, H = 600 Э, I_d = 70 mA.1 – U_{hc} = ground potential; 2 – U_{hc} = - 0,3 kV; 3 – U_{hc} = - 1,5 kV

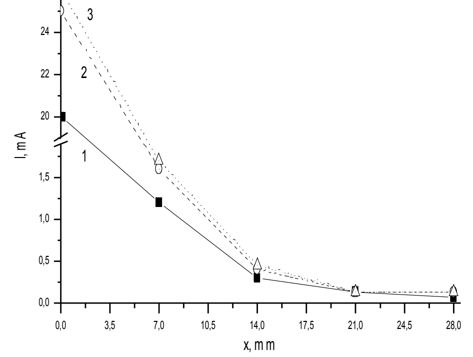

Fig.5. Ion current distribution on the sections of the metal-hydride hollow cathode under negative potential supplying on all sections. p = 4·10^{-3} Torr, H = 600 Э, I_d = 70 mA. 1 – U_{hc} = ground potential; 2 – U_{hc} = - 0,3 kV; 3 – U_{hc} = - 1,5 kV

The currents on the nearby (to anode) sections (1^{st},2^{nd},3^{rd}) are increase along the magnitude of negative biasing increase as for metal-hydride hollow cathode and for copper as well. However in case of metal-hydride hollow cathode the increment of ion current on the cathode sections decreases with increase of negative biasing magnitude and at the magnitudes $U_b < -0{,}3\ kV$ it saturates. For the copper cathode the ion current on the nearby sections increases uniformly with increase of negative bias magnitude on the cathode. The currents on 4^{th} and 5^{th} sections practically do not change out of dependence from the material of the cathode. The different behavior of ion current changing at negative potential supply for the metal-hydride and copper hollow cathodes can be explained by following. In reflective discharge at negative biasing supply on the one of the cathodes the discharge current redistribution takes place that leads to increase of current density and energy of the ions which are bombard such a cathode. The presented effect apparently explains practically linear increasing of current on the nearby sections of copper cathode with increase of negative biasing magnitude. The saturation of the ion current on the sections of metal-hydride hollow cathode with increase of negative biasing magnitude apparently connected with processes of dissociative attachment of slow electrons by vibrationaly-excited hydrogen molecules in the conditions of intensification their desorbtion from the surface of metal-hydride.

At positive potential supply in the range of 0.5...2 kV to the middle section of the hollow cathode while the other were at ground potential the case of modified hollow cathode was realized where additional anode is in the cathode hollow [6].

The discharge current magnitude in this case distinctly reduces and shift of hollow cathode excitation mode is observed towards the higher voltage. Such a behavior was the same for all investigated magnitudes of pressure and magnetic field. In such modified hollow cathode ion confinement worse in comparison with typical hollow cathode and therefore the higher voltage drop on discharge is realized [6]. However applying this scheme of electrodes supply allows to operate of plasma penetration into hollow cathode. Current increasing on the middle section of the hollow cathode leads to current reducing on the 4^{th} and 5^{th} sections and current increasing on 2^{nd} section simultaneously (Fig.6, 7). Such a behavior was observed for all investigated magnitudes of pressure and magnetic field. Moreover at high potential supplying (more than +1.5 kV) on the 3^{rd} section of the hollow cathode the current on 4^{th} and 5^{th} sections reduces up to zero. Thus supplying of positive potential on sections of metal-hydride hollow cathode it is possible to operate of plasma penetration into the hollow of the cathode.

Investigations of ion energy distribution function when the both cathodes are at ground potential have shown that the most probable ion energy is within a rather narrow maximum in the energy range close to discharge potential (Fig.8). Such a behavior of distribution function was observed in whole range of working pressure. The explanation of this fact apparently is that these ions generate mainly in negative glow and without sufficient energy loss at the expense of diffusion along the discharge axis reache the anticathode [7].

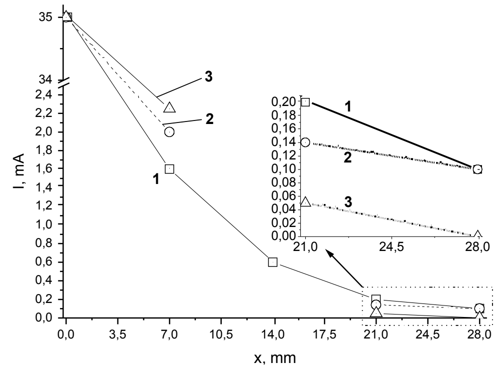

Fig.6. Current distribution along the copper hollow cathode under the positive potential supplying on 3^{rd} section and gas feeding through the hollow.
$P = 8\cdot10^{-4}$ Torr, $H = 600$ Oe, $I_d = 70$ mA.
1 – ground potential, 2 – $U_{3s} = +0{,}5$ kV;
3 - $U_{3s} = +2$ kV

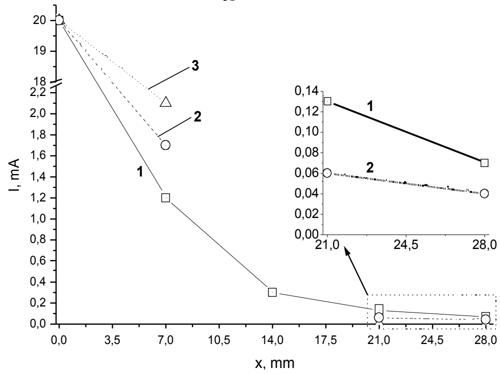

Fig.7. Current distribution along the metal-hydride hollow cathode under the positive potential supplying on 3^{rd} section and gas feeding through the hollow.
$P = 8\cdot10^{-4}$ Torr, $H = 600$ Oe, $I_d = 70$ mA.
1 – ground potential; 2 – $U_{3s} = +0{,}5$ kV;
3 - $U_{3s} = +2$ k

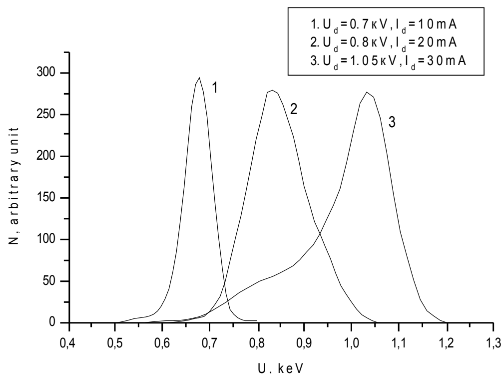

Fig.8. Ion energy distribution functions extracted from reflected discharge with metal-hydride hollow cathode.
$P = 4\cdot10^{-3}$ Torr; $H = 600$ Oe

With the purpose of possibility to operate of ion energy distribution function the negative voltage supply on the hollow cathode relatively to ground potential was realized. It led to discharge voltage drop decreasing. At that the most probable ion energy for discharge with metal-hydride hollow cathode (Fig.9,a) and for check discharge with copper hollow cathode (Fig.9,b) decreases as the value of cathode negative shift increases. However if in case of check discharges such a behavior is rides only by discharge voltage drop decreasing then in case of metal-hydride cathode the most probable energy of extracted ions was less than anode potential and was the value of (0.7...0.8)·eU_a.

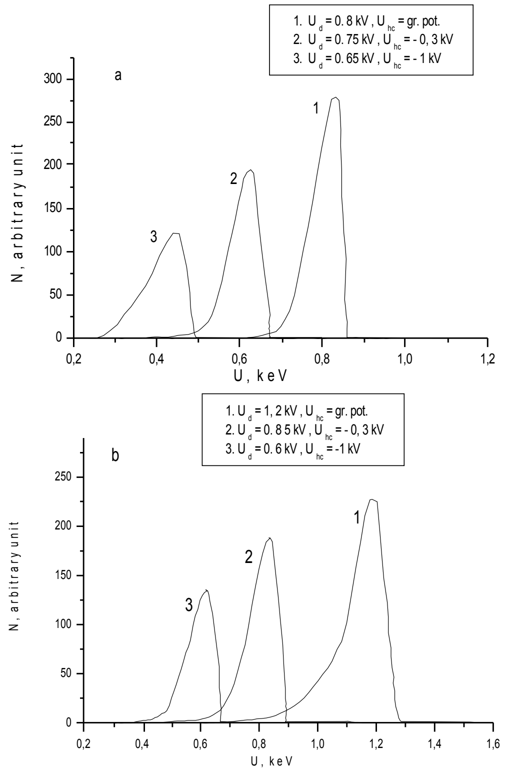

Fig.9. Ion energy distribution functions depending on potential negative shift on the hollow cathode: $P = 4{\cdot}10^{-3}$ Torr; H = 600 Oe; I_d = 20 mA; a – metal-hydride hollow cathode; b – copper hollow cathode

At increasing of negative shift value on metal-hydride hollow cathode the difference between most probable ion energies and anode potential increased. Such an influence of negative glow shift on ion energy distribution function one can explain by following. Negative voltage supply on hollow cathode leads to current density of ions bombarded the surface of the cathode increasing. As a result the quantity of activated hydrogen in the hollow which has reduced ionization potential increases. It leads to increasing of ionization efficiency in the hollow. As a result space potential in this area decreases and as a consequence the most probable ion energy lower than discharge voltage drop value.

It should be pointed out that such an effect is typical only for discharge with metal-hydride hollow cathode as long as at hollow cathode changing on flat one the shift of maximum on distribution function at negative shift supplying practically was not observed.

Thus as a result of carried out experimental investigations it has been shown that at activated hydrogen desorbtion from the surface of metal-hydride cathode the possibility to form hydrogen ion beams with the energy lower than in case of cathode materials applying that does not content hydride phases appears. It is conditioned on reduced ionization potential of activated hydrogen. Metal-hydride hollow cathode applying allows to widen the range of ion energy distribution function controlling aside less energy values at the expense of negative shift supplying on such a cathode.

CONCLUSIONS

Thus, it was shown that in case of metal-hydride using as a material of hollow cathode plasma penetrates into the hollow sufficiently deeper then in case of copper hollow cathode but the ion current on the cathode sections lower. Applying such reversible sorbents of hydrogen allows to provide additive hydrogen supply directly through the hollow and lower values of bombarded ion current decrease the sputtering such materials. It was shown the possibility to operate the plasma penetration into the cathode hollow by the potentials supplying on it's sections. The experimental investigations of metal-hydride hollow cathode influence on energy of extracted ions from plasma ion source based on reflective discharge. The opportunity to operate efficiently of distribution function of extracted from reflective discharge ions by the changing of negative electric potential on the metal-hydride hollow cathode has been shown.

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ВЛИЯНИЕ АКТИВИРОВАННОГО ВОДОРОДА НА ХАРАКТЕРИСТИКИ РАЗРЯДА ПЕННИНГА С ПОЛЫМ КАТОДОМ

В.Н. Бориско, Е.В. Клочко, И.Н. Середа, А.Ф. Целуйко

Представлены результаты экспериментальных исследований отражательного разряда с секционированным полым катодом. В качестве конструкционных элементов полого катода использовался геттерный сплав $Zr_{50}V_{50}H_x$, способный к обратимому поглощению водорода при низком давлении. Показано, что применение такого материала приводит к значительно большему проникновению плазмы в катодную полость. Исследована возможность управления проникновением плазмы в металлогидридный полый катод путем варьирования потенциалами на его секциях. Исследованы особенности функции распределения извлекаемых ионов из такого разряда.

ВПЛИВ АКТИВОВАНОГО ВОДНЮ НА ХАРАКТЕРИСТИКИ РОЗРЯДУ ПЕННІНГА З ПОРОЖНИСТИМ КАТОДОМ

В.М. Бориско, Є.В. Клочко, І.М. Середа, О.Ф. Целуйко

Представлено результати експериментальних досліджень відбивного розряду з секціойованим порожнистим катодом. В якості конструкційних елементів порожнистого катоду використовувався гетерний сплав $Zr_{50}V_{50}H_x$, що здатен оборотно поглинати водень при низькому тиску. Показано, що застосування такого матеріалу приводить до значно більшого проникнення плазми в катодну порожнину. Досліджено можливість керування проникненням плазми в металогідридний порожнистий катод шляхом варіювання потенціалами на його секціях. Досліджено особливості функції розподілу іонів, що витягаються з такого розряду.