PIG WITH METAL-HYDRIDE CATHODE UNDER ION-STIMULATED DESORBTION OF HYDROGEN

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The results of experimental investigation of penning type charged particles source with metal-hydride water-cooled cathode are presented. The feature of investigation is hydrogen ion-stimulated desorbtion from metal-hydride as a way of working gas feeding. The influence of ion-stimulated desorbtion on emissive source characteristics was studied. In outflowing in axial direction charged particles flow the dynamic of energy distribution function of electrons and ions was carried out and their dependence on discharge external parameters was determined.

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INTRODUCTION

Metal-hydride cathode (MH-cathode) applying in plasma sources of charged particles is of interest for modern science. Desorbed from the cathode hydrogen due to exposure to heat is in activated state and has the ionization potential on 0.5 eV lower and ionization cross-section in 1.5 times higher than common molecular balloon hydrogen [1]. This is sufficiently raising the efficiency of an ion source. The complementary advantages of MH-cathode using are compactness and safety of hydrogen store as well as possibility to realize the local gas feeding. But for all that MH-cathode using leads to discharges parameters and characteristics of outflowing charged particles flow changing [2]. It concerned with state changing of feeding hydrogen [3].

The problem in creation of working source is strong dependence of desorbed hydrogen flow on MH-cathode temperature that makes difficult to stabilize the discharge regime. For solving this problem the authors offer to apply forced water-cooling of MH-cathode. In this case maintaining temperature of MH-cathode lower than hydride phase decomposition one, the hydrogen desorbtion should be realized due to ion-stimulated processes and desorbtion velocity should be determined only by ion current bombardment of metal-hydride surface.

1. EXPERIMENTAL SETUP

The experimental investigations were carried out in discharge cell of penning configuration set in longitudinal magnetic field (Fig. 1). The cylindrical anode was 3.7 cm in diameter and 3 cm in length. MH-cathode (2) was a disk 2 cm in diameter and 0.5 cm in thick. It was pressed from powder mixture of saturated with hydrogen $Zr_{50}V_{50}H_x$ alloy and copper stuff. The initial saturation of MH-cathode with hydrogen was about 900 cm^3 at normal conditions

MH-cathode was placed in copper cathode-holder (3) 2.5 cm in diameter, which has water-cooling. For ensuring a good heat contact of MH-cathode with cathode-holder its surface was covered with heat-conducting spread. The MH-cathode temperature was controlled by thermocouple (4). The copper cathode-reflector (5) 2 cm in diameter and 0.5 cm in thick has a hole at the center 0.5 cm in diameter. Behind the hole the collector (6) for outflow charged particles current measurement was set. At energy spectra investigation by the method of retarding field the collector was changed on 4th electrode electrostatic energy-analyzer. On the first grid the tearing potential +3 kV or -0.2 kV for separation of electron or ion part in outflow current correspondingly was supplied. The distance between anode and cathodes was 1 cm. In check experiments MH-cathode was changed with copper one of same form and dimensions.

The whole electrode system was fixed inside the quartz cylinder played a role of electrostatic shield.

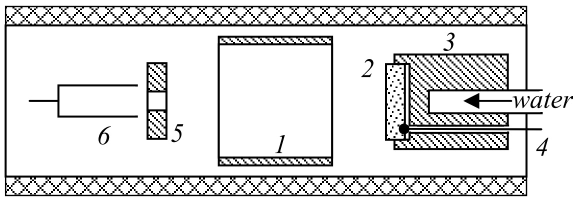

Fig. 1. The scheme of discharge cell: 1 – anode; 2 – MH-cathode; 3 – cathode-holder; 4 – thermocouple; 5 – cathode-reflector; 6 – collector

The residual pressure in vacuum chamber not exceeds $3\cdot10^{-6}$ Torr. The investigations were carried out at the pressure of $10^{-6}\ldots10^{-4}$ Torr.

2. RESULTS AND DISCUSSION

The forced MH-cathode cooling is shown to stabilize the discharge working pressure and eliminates hydrogen kick due to uncontrolled thermal decomposition of hydride phases. Low temperature of MH-cathode (lower than hydride phases decomposition one) ensures hydrogen desporbtion only by ion-stimulated processes. It gives the possibility to operate the hydrogen desorbtion velocity by current discharge. At that hydrogen consumption sufficiently reduces and time of the source continuous work raises.

Fig. 2 shows typical dependences of pressure (a), discharge current (b) and collector current (c) on discharge voltage. The discharge was ignited on residual pressure $P = 5\cdot10^{-6}$ Torr. There is no external gas supply so the pressure change during the discharges working could be unambiguously joined with hydrogen desorbtion from MH-cathode.

One can see that in case of two copper cathodes the pressure changes weakly (dotted line on Fig. 2,a). At the same time in case of MH-cathode (solid line) starting from discharge voltage $U_d \approx 2$ kV (it corresponds to discharge current $I_d \approx 0.2$ mA (see Fig. 2,b) the pressure rises due to hydrogen desorbtion under ion-stimulated processes. Increasing I_d up to 1 mA leads to working pressure set up on the level of $2{\cdot}10^{-5}$ Torr.

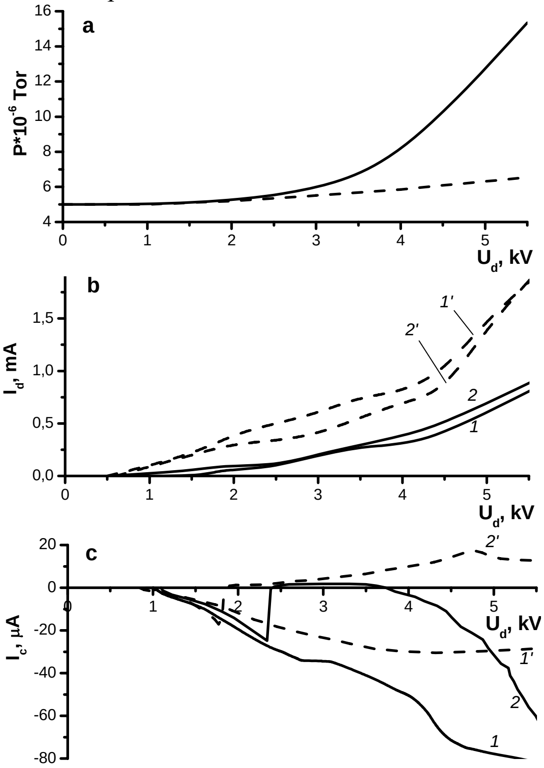

Fig. 2. Dependences of pressure (a), discharge current (b) and collector current (c) on discharge voltage at initial pressure $P = 5{\cdot}10^{-6}$ Torr. Dotted line corresponds to check discharge, solid line – discharge with MH-cathode. 1 – MH-cathode, H = 600 Э; 1' – check discharge; 2 – MH-cathode, H = 1000 Э; 2' – check discharge

It is important that the pressure in vacuum chamber is determined by discharge current and at changing it in one or another side the pressure rapidly changes and stabilizes on the new level.

The current-voltage characteristics presented in Fig. 2,b are show to require heightened voltage drop in case of discharge with MH-cathode as compared with check one. The reason is repeatedly discussed, for instance in [4], and obviously concerned with dissociative capture of slow electrons by vibrationaly excited molecules of desorbed hydrogen.

There are differences in outflowing from discharge flows of charged particles (see Fig. 2,c) as well. At high magnetic field the discharge with MH-cathode works at three-regimes (curve 2). The first one is characterized by axial electron yield ($U_d \approx 1…2.3$ kV), the second one – by ion yield ($U_d > 2.4$ kV) and the third one – again by electron yield ($U_d > 3.5$ kV). Such a behavior was typical in the range of magnetic field changing from 700 up to 1000 Oe. These regimes are in detail described in [2, 3] and concerned with oscillation processes in anode layer. There is no 3rd regime when using both copper cathodes (curve 2').

At low magnetic fields about 500…600 Oe both in case of MH-cathode and in check experiments the collector was registered only negative current value (see curves 1 and 1' in Fig. 2,b). The collector current in discharge with MH-cathode is about in two times bigger than in check one that obviously due to transition of the first regime straight away to the third one. The check discharge keep works in the first regime (curve 1'). It should be pointed out that such a behavior in the check discharge was only at residual pressure working. At even minor balloon hydrogen feeding the collector current turned in to positive values already at $U_d > 2$ kV: the discharge transits to the second regime.

In the other side the discharge with MH-cathode transited to three-regime working only as from the pressure of $3{\cdot}10^{-5}$ Torr (Fig. 3). But for all that balloon hydrogen was feed for working pressure set up. (In our case the only hydrogen desorbtion due to ion-stimulated processes was not enough).

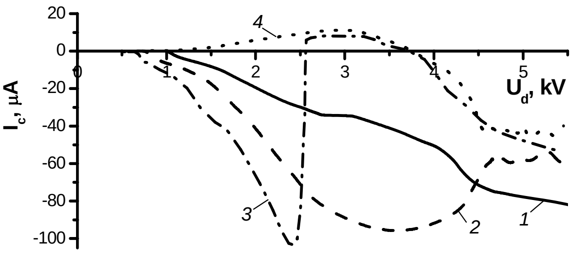

Fig. 3. The dependence of collector current on discharge voltage at H = 600 Oe for different pressures. 1 – $P = 5{\cdot}10^{-6}$ Torr; 2 – $P = 2{\cdot}10^{-5}$ Torr; 3 – $P = 3{\cdot}10^{-5}$ Torr; 4 – $P = 5{\cdot}10^{-5}$ Torr

Such a behavior was typical either at pressure or at magnetic field rising. It is agreed with results carried out in [2]. At magnetic field lower than 500 Oe the discharge works only in second regime (with ions yield in axial direction) in whole investigated range of pressure.

The analysis of energy spectra of outflowing charged particles flow revealed a number of peculiarities as well. At working on residual pressure electrons have weak dependence of energy both on discharge voltage and magnetic field. The most likely electron energy there is about 20 eV (Fig. 4,a), and the main part of electrons posses energy in the range from 10 to 75 eV.

Increasing of initial pressure due to external balloon hydrogen feeding leads to widening of electron energy distribution function and maxima shifting in direction of bigger energy values (Fig. 4,b). It is important to note the fact is most pronounced at the pressure of $P = 3{\cdot}10^{-5}$ Torr, which corresponds to discharge transition in to three-regime working (see curve 3 in Fig. 3) and concerned with extra energy getting of electrons against an intensive oscillation development in the discharge [3]. The same dependence of distribution function is registered at more high values of magnetic field.

The reversed situation is observed at ion component in outflowing axial flow investigation. Magnetic field increasing leads to significant rising of ion energy (Fig. 5). If at H = 600 Oe ion energy was about 8% from discharge voltage then at H > 700 Oe – about 50% with tendency to saturation at discharge voltage drop rising.

At heightened values of magnetic field or initial pressures in chamber the average ion energy has a weak dependence on these parameters.

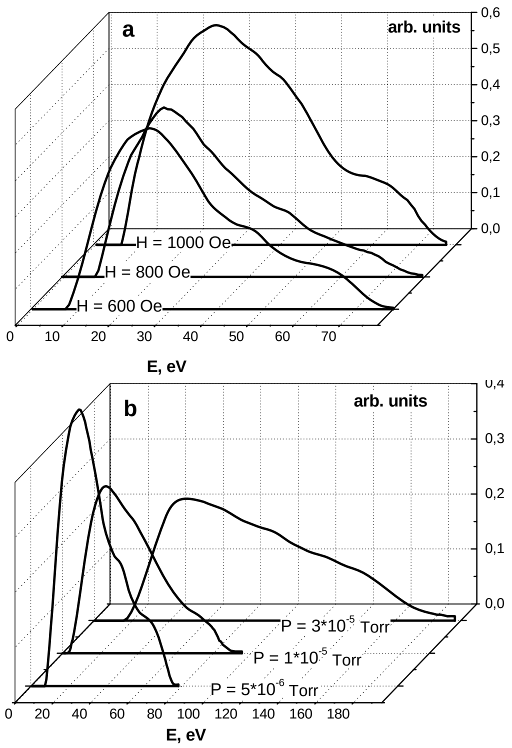

Fig. 4. Electron energy distribution function at U_d = 4.5 kV for constant pressure P = $5\cdot10^{-6}$ Torr (a) and for constant magnetic field H = 600 Oe (b)

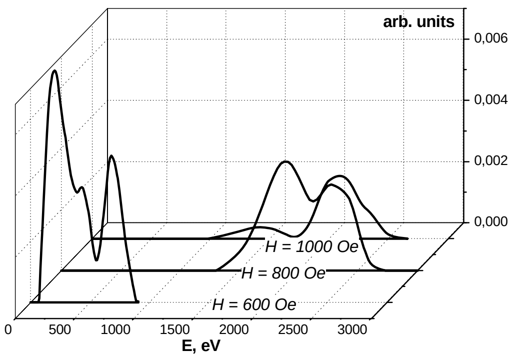

Fig. 5. Ion energy distribution function at U_d = 4.5 kV for initial pressure P = $5\cdot10^{-6}$ Torr

Thus, in the range of external parameters described with curves 1 and 2 in Fig. 3 (P < $3\cdot10^{-5}$ Torr, H ≈ 500…600 Oe), when the second regime of discharge working is absent, the average energy of ions outflew along the axis is small. The electron energy possesses a minimal value as well. In this case ionization of desorbed hydrogen with oscillated along the axis electrons occurs mainly by the axis where the space potential is small. The discharge transition to the three-regime working causes by instability development in anode layer [2, 3]. Electron energy at that rises, and the area of main ionization shifts from the axis in to anode layer. And last but not the least, forced water cooling of MH-cathode is shown to stabilize the discharge working pressure and provides hydrogen desorbtion only by ion-stimulated processes.

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РАЗРЯД ПЕННИНГА С МЕТАЛЛОГИДРИДНЫМ КАТОДОМ ПРИ ИОН-СТИМУЛИРОВАННОЙ ДЕСОРБЦИИ ВОДОРОДА

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Представлены результаты экспериментального исследования источника заряженных частиц пеннинговского типа с металлогидридным водоохлажденным катодом. Особенность исследования заключается в способе напуска рабочего газа за счет ион-стимулированной десорбции водорода из металлогидрида. Изучено влияние ион-стимулированной десорбции на эмиссионные характеристики источника. В выходящем из источника в аксиальном направлении потоке заряженных частиц исследована динамика функций распределения ионов и электронов по энергиям и определена их зависимость от внешних параметров разряда.

РОЗРЯД ПЕНІНГУ З МЕТАЛОГІДРИДНИМ КАТОДОМ ПРИ ІОН-СТИМУЛЬОВАНІЙ ДЕСОРБЦІЇ ВОДНЮ

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Представлено результати експериментального дослідження джерела заряджених частинок пенінговського типу з металогідридним катодом, що охолоджується. Особливість дослідження полягає в способі напуску робочого газу за рахунок іон-стимульованої десорбції водню з металогідриду. Вивчено вплив іон-стимульованої десорбції на емісійні характеристики джерела. У вихідному із джерела в аксіальному напрямку потоці заряджених часток досліджена динаміка функцій розподілу іонів й електронів по енергіях і визначена їхня залежність від зовнішніх параметрів розряду.