PLASMA PARAMETERS IN PIG WITH METAL-HYDRIDE CATHODE UNDER DIFFERENT WAYS OF HYDROGEN SUPPLY

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In the paper plasma density dynamic on the axis of Penning discharge with metal-hydride cathode in axial electron flow emission regime have been experimentally investigated. The ion-stimulated desorption influence on emissive characteristics of the source were studied. Sufficient plasma density increasing up to $n \approx 10^{10}$ cm^{-3} was established on the discharge axis when metal-hydride cathode was used. Comparable analysis of the plasma density dynamic under different ways of hydrogen supply was carried out.

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INTRODUCTION

Developing of plasma devises which are need no external sources of plasma-forming material is the great interest for modern science. In case of hydrogen using as working gas the metal-hydride cathode applying is perspective. Such alloys are able to reversibly store hydrogen with following it's desorption to a consumer. Together with compactness and safety of hydrogen storage it allows to locally supply hydrogen in activated state at the discharge area of interest [1]. Hydrogen desorption is determined mainly by thermal impact due to discharge current. However a number of experiments carried out on Penning discharge with metal-hydride cathodes (MH-cathodes) revealed sufficient differences in discharge working compared to ones where the cathodes did not form hydride phases [2 - 5]. So, the addition discharge regime with axial electron emission was revealed in [2]. In [3] the influence of metal-hydride cathode on electron emission was investigated. In [4] the experimental simulation of hydrogen desorption by the way of hydrogen supply through the cathode of special design was carried out. And in [5] the possibility of discharge working only on desorbed from metal-hydride hydrogen due to ion stimulation processes was investigated. The paper is continuation of the experiments and devoted to investigation and generalization of plasma parameters of Penning discharge with MH-cathode under different ways of hydrogen supply.

1. EXPERIMENTAL SETUP

The experimental investigations were carried out on penning-type discharge cell represented in Fig. 1.

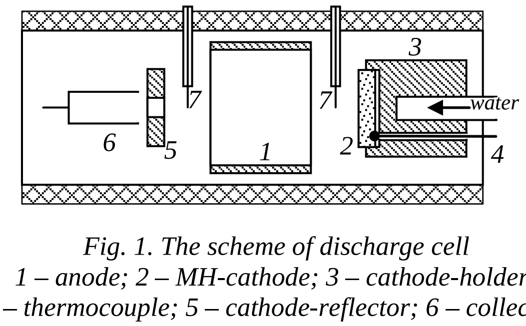

Fig. 1. The scheme of discharge cell
1 – anode; 2 – MH-cathode; 3 – cathode-holder; 4 – thermocouple; 5 – cathode-reflector; 6 – collector; 7 – Langmuir probes

In experiments three types of cathodes were used. First one was MH-cathode pressed from powder mixture of saturated with hydrogen $Zr_{50}V_{50}H_x$ alloy and copper stuff with initial saturation of hydrogen about 900 cm^3 at normal conditions. It was just set in discharge. Second one was the same MH-cathode but with water-cooling and third one was copper cathode of special design with hydrogen supply for simulation of hydrogen desorbtion. The cathode-reflector was made from copper and has a hole at the center 0.5 cm in diameter. In check experiments two solid copper cathodes were used. Behind the hole in cathode-reflector a collector was set.

In simulation of hydrogen desorbtion experiments balloon hydrogen was locally fed through the thin holes in working surface of copper cathode. The ratio between local (through cathode) and additional (in vacuum chamber) flows of supplied hydrogen as well as intensity of external magnetic field were pick out the same as in [2] at third regime of discharge with MH-cathode.

For plasma parameters investigation two Langmuir probes 4 mm in length and 0.3 mm in diameter were used (7). They were set in the axis of the discharge in a half distance between anode-cathode. The cathodes were under grown potential, on the anode positive potential was supplied.

The residual pressure in vacuum chamber not exceeds $5 \cdot 10^{-6}$ Torr. The investigations were carried out at the pressure of $10^{-6}…10^{-4}$ Torr. Working pressure higher than residual one was set by initial balloon hydrogen feeding in to vacuum chamber.

2. RESULTS AND DISCUSSION

The typical collector currents in case of the discharge worked only on desorbed from MH-cathode hydrogen are presented in Fig. 2. One can see the discharge behavior does not sufficiently change from the previous experiments with the MH-cathode with additional external hydrogen supply in vacuum chamber [5]. The discharge is still characterized by three working regime. The first one is with electron yield ($U_d \approx 1…2.5$ kV). The second one is with ion yield ($U_d > 2.4$ kV) and the third one – again with 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 were in detail described in [3, 4] and concerned with oscillation processes in anode layer. There is was no 3rd regime when both copper cathodes had used (curve 3'). Simultaneous MH cathode cooling was used for pressure stabilizing and did not influence on collector current.

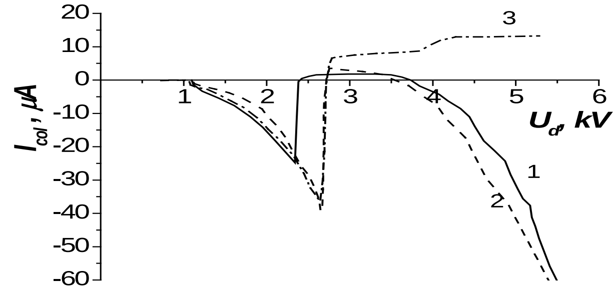

Fig. 2. Dependence of collectors current on discharge voltage at different cathodes, P=5·10^{-6} Torr, H=1 kOe. 1 – MH cathode; 2 – water-cooled MH cathode; 3 – check experiment

The first two regimes of discharge working are well known [2], so the main attention in the paper was devoted to third regime. This regime starts only in case of saturated with hydrogen MH-cathode applying [4]. The plasma density on the discharge axis sufficiently rises. And exactly in third regime this process is the most pronounced.

The fact of interest when addition MH-cathode cooling leads to not only hydrogen working pressure stabilizing, but also provides uniform plasma density profile along the axis of discharge cell (Fig. 3, curve 3) despite of intense hydrogen flow only by the MH-cathode side. The curve of plasma density by the cathode-reflector is not present because of it almost full overlap with curve 3. At the same time if the MH-cathode does not cooling, the plasma density gradient aside MH-cathode will appears and it rises along discharge current increasing (see Fig. 3, curves 1 and 2). It is in good agreement with previous experiments because apart from ion-stimulated desorption of hydrogen from the MH-cathode surface there are mechanisms of thermal decomposition of hydride phases and hydrogen desorbed from the material volume [1, 2].

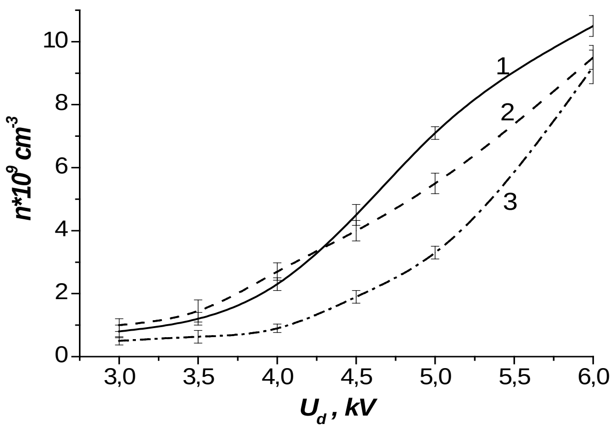

Fig. 3. Plasma density on the axis of PIG with different cathodes depending on discharge voltage, P = 5·10^{-6} Tor, H = 1 kOe. 1 and 2 – by the MH-cathode and by the opposite side correspondingly; 3 – by the MH water-cooled cathode

In case of hydrogen supply due to only ion-stimulated processes the desorption velocity determines only by discharge current and adjusts for needful plasma density in the discharge cell providing. The data about experiments with two copper cathodes are not presented because on this stage the experiments were carried out only on residual pressure under hydrogen desorption only from MH-cathode.

Fig. 4 demonstrates the characteristic curves of plasma density depending on magnetic field for discharge voltage 3.5 kV – collector current compensation and for 5.0 kV – negative collector current (see Fig. 2). One can see there is a trend for plasma density decreasing in the range of magnetic field of 600…800 Oe. When magnetic field rises in regime of collector current compensation (U_d = 3.5 kV) the trend kept on, but at U_d = 5.0 kV the density increases. But plasma density in case of cooled MH-cathode is sufficiently lower, then for MH-cathode without simultaneous cooling. Such a behavior is obviously due to nonlinear dependency of discharge current on magnetic field under the circumstances of anode layer instability development [6].

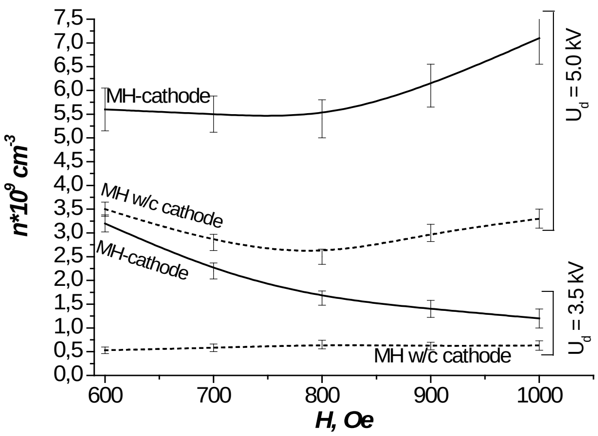

Fig. 4. Plasma density on the axis of PIG with different cathodes depending on magnetic field intensity, P = 5·10^{-6} Torr

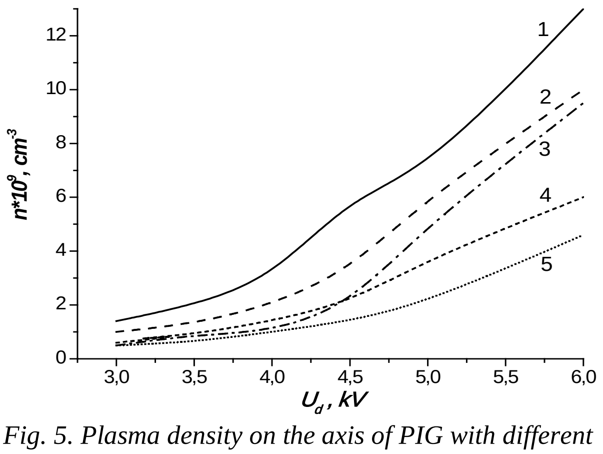

Fig. 5. Plasma density on the axis of PIG with different cathodes depending on discharge voltage, P = 3·10^{-5} Torr, H = 1 kOe. 1 and 2 – by the MH-cathode and by the opposite side correspondingly; 3 – by the MH water-cooled cathode; 4 – by the cathode with balloon H_2 supply; 5 – check experiment

In Fig. 5 the summary pattern of plasma density dependence on discharge voltage is presented for different ways of hydrogen supply. Here again hydrogen supply was carried out by the side of a cathode but there was also general hydrogen supply into the vacuum chamber. The behavior of curves 1, 2 and 3 is the same as presented above in Fig. 3 and explained the same reasons then for experiments on residual pressure. Curve 4 corresponds to desorption simulation experiment by the way of hydrogen supply through the cathode of special design. The experimental set up and problem statement are described in detail in [4]. Curve 5 corresponds to check experiments with two copper cathodes.

One can see that independently on the way of hydrogen supply the highest values of the plasma density are achieved at MH-cathode applying. Also it could be concluded that MH-cathode applying increases the efficiency of plasma forming due to mutual influence of discharge current on hydrogen desorption in non equilibrium state. So, MH-cathode is not only the local gas generator, but also increases working efficiency of the plasma device in general.

The electron temperature was about 25 eV and authors did not observe any sufficient differences in electron temperature behavior under different ways of hydrogen supply. The same could be said about plasma and floating potential, which were investigated in [3].

CONCLUSIONS

Thus, at discharge working on hydrogen desorbed from MH-cathode the plasma density sufficiently increases. The highest values of the density $n \approx 10^{10}$ cm^{-3} are achieved by the MH-cathode without simultaneous cooling dependingless on initial gas environmental. From the opposite side by the cathode-reflector the plasma density is some lower so the gradient towards from the MH-cathode to cathode-reflector occurs. The additional MH-cathode cooling decreases hydrogen desorption velocity, and the plasma density takes the lower values then in above case and the density gradient along the axis practically disappears. At working on balloon hydrogen dependingless on the way of its supply there is no third regime with axial electron emission and plasma density sufficiently lower.

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ПАРАМЕТРЫ ПЛАЗМЫ В РАЗРЯДЕ ПЕННИНГА С МЕТАЛЛОГИДРИДНЫМ КАТОДОМ ПРИ РАЗНЫХ СПОСОБАХ НАПУСКА ВОДОРОДА

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Экспериментально исследована динамика плотности плазмы на оси разряда Пеннинга с металлогидридным катодом в режиме эмиссии аксиального потока электронов. Изучено влияние ион-стимулированной десорбции водорода на эмиссионные характеристики источника. Установлено значительное увеличение плотности плазмы $n \approx 10^{10}$ см$^{-3}$ на оси разряда с металлогидридным катодом. Проведен сравнительный анализ динамики плотности плазмы при различных способах напуска водорода в ячейку.

ПАРАМЕТРИ ПЛАЗМИ В РОЗРЯДІ ПЕННІНГА З МЕТАЛОГІДРИДНИМ КАТОДОМ ПРИ РІЗНИХ СПОСОБАХ НАПУСКУ ВОДНЮ

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Експериментально досліджена динаміка густини плазми на осі розряду Пеннінга з металогідридним катодом у режимі емісії аксіального потоку електронів. Вивчено вплив іон-стимульованої десорбції водню на емісійні характеристики джерела. Встановлено значне збільшення щільності плазми $n \approx 10^{10}$ см$^{-3}$ на осі розряду з металогідридним катодом. Проведено порівняльний аналіз динаміки щільності плазми при різних способах напуску водню в розрядний проміжок.