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PENNING-TYPE H^- ION SOURCE WITH METAL HYDRIDE CATHODE IN PULSATING REGIME

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The features of H^- ion emission from gas-feed-free Penning-type ion source with metal hydride cathode have been studied in pulsating regime. The metal hydride cathode provided local injection of hydrogen in activated state and impacts on Penning discharge ability to emit H^- ions in the longitudinal direction. For stimulation of pre-excited hydrogen desorption from metal hydride the voltage pulse (4.5 kV, $\tau \approx 15$ μs) was performed against the background constant voltage of 6 kV on the anode of the discharge. The H^- ion current of about 0.2 mA was obtained.

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INTRODUCTION

The independence of neutralization efficiency at high beam energy determines the main fields of H^- ions application for the production of neutral beam for fusion [1] and medical radionuclides in cyclotrons [2]. The construction of H^- sources is usually based on two well-known physical mechanisms [3]. It is the direct formation of H^- ions in plasma, when highly rovibrationally excited molecules H_2* produced with fast electrons, dissociate after colliding with slow electrons. The resulting current of H^- ions is determined by the flow of neutral hydrogen and is limited by the destruction processes of negative ions, when the pressure in cold plasma rises more than 0.1 Pa [4]. Next one is the production of H^- ions on the plasma electrode surface covered with cesium [5]. It gives much greater intensity of H^- current, but cesium leakage to the acceleration zone can cause a breakdown. So, the search for material for efficient cesium-free ion source operation is currently the great challenge [6].

Metal hydride application as a plasma electrode material is known to increase the production of negative hydrogen ions due to H_2* molecules activation at the metal hydride surface, which then can be easily converted to H^- ions by dissociative electron attachment [8]. Previously we reported about successful application of metal hydride cathode in Penning negative ion source [7], where we obtained the H^- current of 5 μA at a power input of 10 W. For further increase of source performance, the uptake rate of pre-excited hydrogen molecules from the cathode should be raised. The purpose of this paper is to increase the yield of H^- ions by the pulsating regime implementation followed by the stimulation of pre-excited hydrogen desorption from metal hydride due to the current of charged particles impact from plasma.

1. EXPERIMENTAL SETUP

The scheme of a Penning cell used as an ion source is shown in Fig. 1. Hydrogen plasma is generated between a metal hydride cathode (1), a copper cathode (5) and a tube-shaped anode (4) with a longitudinal magnetic field H_{z0} = 0…0.1 T. The specified dimensions of the cell were chosen experimentally for the stable operation of the discharge without break-downs. The metal hydride cathode was produced from hydride-forming alloy $Zr_{50}V_{50}$ with the hydrogen amount absorbed by the material on the level of 190 cm^3/g at atmospheric pressure and room temperature. Temperature stabilization of metal hydride at a level which is lower than the temperature of thermal destruction of hydride phase ensures activated hydrogen H_2* uptake mainly by ion-stimulated processes from the surface of metal hydride locally to the cathode region.

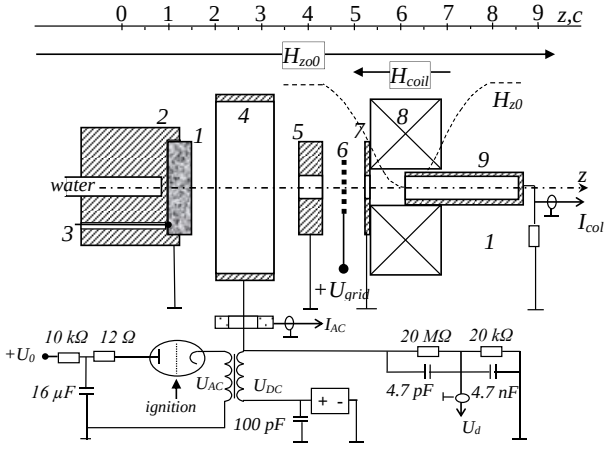

Fig. 1. The scheme of a Penning-type ion source: 1 – metal hydride cathode; 2 – cathode-holder; 3 – thermocouple; 4 – anode; 5 – copper cathode with an aperture; 6 – reflecting grid; 7 – electrons collector; 8 – filter magnetic coil; 9 – H^- ion collector; H_{z0} – main axial penning magnetic field (H_{z0} =0…0.1 T); H_{coil} – reverse magnetic field of the filter

Hydrogen activation changes the Penning discharge properties and a flow of negatively charged particles together with positive ions starts yielding along the external magnetic field through an aperture in the cathode (5). The separation of negative ions H^- from electrons and positive ions is performed by electromagnetic filter, which consists of a grid (6) for positive ions retarding, a magnetic coil (8) to divert electrons, a collector of diverted electrons (7) and a collector of extracted axial beam of H^- ions (9). The coil (8) creates a reverse magnetic field H_{coil}. The required values of the resulting field H_{z0} and grid potential (U_{grid} = 1.65 kV) in the filter is calculated from the analysis of electrons and H^- ions

trajectories by numerical solution of a motion equation in axially symmetric electric and magnetic fields [7]. The grid (6) in addition to the retarding function for positive ions accelerates electrons and H^- ions to approximately the same energy followed by the successful separation in the magnetic field H_{z0} of the filter.

The discharge operation is ensured by applying a positive potential to the anode. The electrical circuit provides the supply of pulse voltage of 4.5 kV against the background voltage U_d of 6 kV. The residual pressure in the vacuum chamber was 0.2 mPa.

2. RESULTS AND DISCUSSION

The ability of Penning source with metal hydride cathode of emitting negative particles in longitudinal direction was described in [7]. It occurs at low pressure, high magnetic field and discharge voltage, when a field-free plasma region is formed along the axis, containing electrons oscillating between the cathodes. Discharge voltage drops in the region of negative space charge layer close to an anode [10]. The cathode layer may still present, but with low voltage drop. H^- ions are formed close to the metal hydride cathode due to the dissociative attachment of slow electrons (2…4 eV) to pre-excited hydrogen molecules H_2*, which are desorbed from metal hydride due to ion-stimulated mechanism under the influence of ion current from plasma [8]. The ion current determines the rate of desorption and the equilibrium pressure in the discharge volume [11]. So, the easiest way of improving the efficiency of H^- production is to intensify the desorption rate by the increasing of ion current from plasma [3].

To implement this idea, we used pulsating regime of gas-feed-free Penning type H^- ion source with metal hydride cathode, when the voltage pulse of 4.5 kV was performed against the background constant voltage of 6 kV on the anode. In case of only pulse regime, the only surface of metal hydride works. And after several pulses, when the stored in surface layer hydrogen has been evacuated, the efficiency of H^- production drops. In pulsating regime, due to the energy transfer from background continuous discharge, hydrogen releases from thicker surface layer or even from the whole volume of metal hydride.

The oscillograms of discharge voltage U_d, pulse discharge current I_d and H^- current are shown in Fig. 2. The distortion of the I_d curve especially in the beginning of the pulse is a consequence of the application of Savitzky-Golay smoothing method. However, despite the distortion, it is clearly seen the coincidence of I_d and H^- current peaks at $t \sim 10$ μs, which pointed on the intensification of activated hydrogen desorption and the increasing of H^- production efficiency.

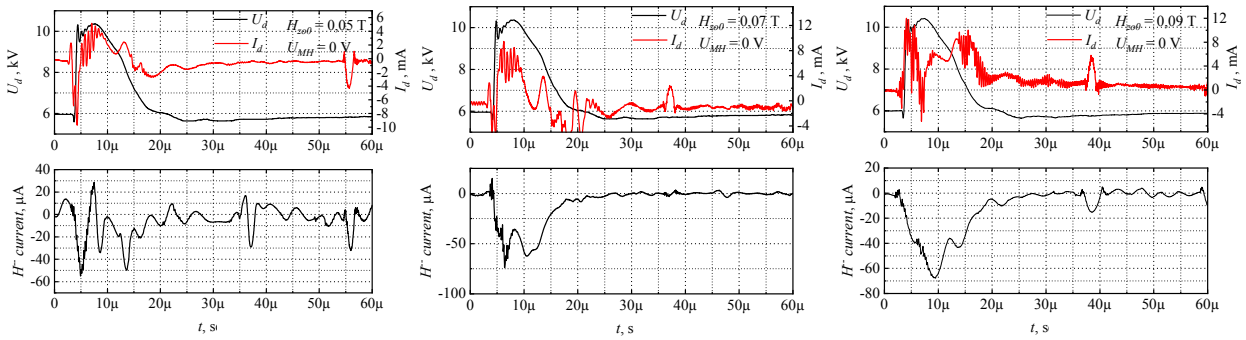

Fig. 2. The oscillograms of discharge voltage U_d pulse discharge current I_d and H^- current at P = 0.2 mPa

A strong dependence of the H^- current on external magnetic field can be explained by the discharge transition to another mode, when the increase of pressure during a pulse leads to a jump of the voltage drop from the anode layer to the cathode and makes it difficult for negative particles of escaping along the axis [12]. But according to the estimations performed in [12] high magnetic field suppresses the discharge transition and the maximum values of H^- current is observed only for high magnetic field H_{z0} = 0.07…0.1 T.

Sufficient enhance of negative current output can be achieved by the supply of negative potential on metal hydride cathode U_{MH}. Due to central field-free plasma region negative particles are additionally pushed out. A positive electrical bias on the cathode-reflector did not lead to any significant result, which testifies to the creation of H^- ions near the metal hydride cathode followed by the pushing them out by electrical bias. Fig. 3 shows the dependence of the value of H^- current on U_{MH} at different external magnetic field H_{z0} in constant regime of discharge operation at U_d of 6 kV.

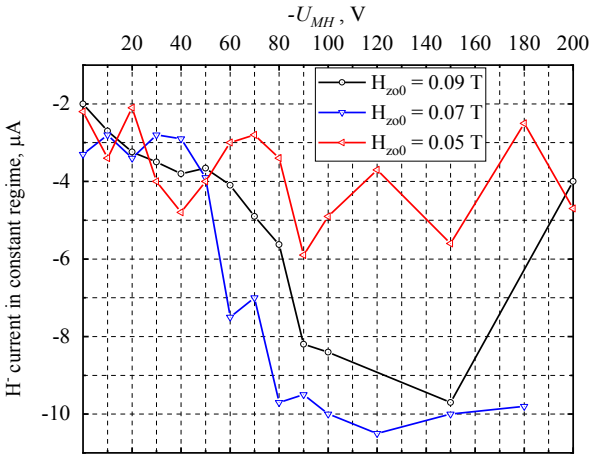

Fig. 3. The dependence of H^- current on U_{MH} in constant regime U_d = 6 kV

Fig. 4 represents the same, but when the pulse voltage of 4.5 kV was supplied against the background U_d of 6 kV.

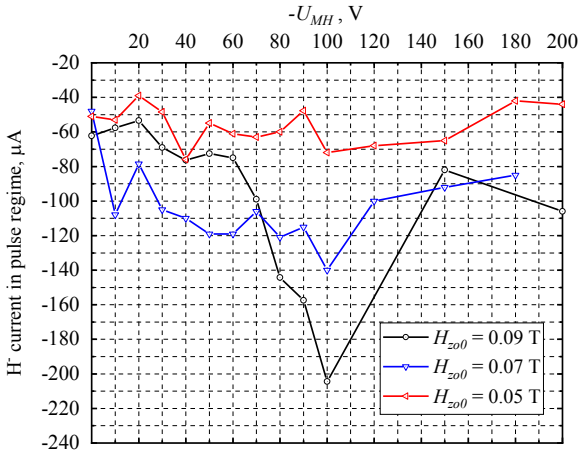

Fig. 4. The dependence of H^- current on U_{MH} in pulsating regime (U_d = 6 kV + 4.5 kV in pulse)

In both cases, there is a general trend of increasing the H^- current from the U_{MH} value of about -60 V with following decline after -120 V. This behavior is determined by the temperature of plasma electrons (T_e), which have Boltzmann distribution and are slowed down in the cathode layer [9].

According to the calculations performed in [9], the higher values of T_e, the closer the reflection point of plasma electrons to the cathode surface and higher values of U_{MH} is needed for efficient formation and ejection of H^- ions.

Reaching the maximum of H^- current at certain U_{MH} is due to the competitive processes of H^- ion production and destruction, because increasing of U_{MH} pushes the formation area of H^- ions away from the surface, and T_e increasing reduces the cross section of H^- ion formation.

CONCLUSIONS

The efficient production of H^- ions occurs due to the dissociative attachment of thermal electrons to activated hydrogen molecules desorbed from metal hydride cathode. Negative electrical bias of metal hydride cathode contributes to a more efficient output of negative ions along the axis of the Penning cell. The value of electrical bias is determined by the temperature of plasma electrons ejected from anode layer on the cathodes. When it takes -100 V, the current of H^- ions reaches the maximum value of about 0.2 mA. High magnetic field suppresses the potential redistribution in the cell and the maximum values of H^- current is observed only for high magnetic field H_{z0} = 0.07…0.1 T, when field-free plasma region is formed along the axis.

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ДЖЕРЕЛО ІОНІВ H^- ПЕННІНГІВСЬКОГО ТИПУ З МЕТАЛОГІДРИДНИМ КАТОДОМ У ПУЛЬСУЮЧОМУ РЕЖИМІ

І. Середа, Я. Гречко, М. Азарєнков

Досліджено особливості емісії іонів H^- джерела іонів пеннінгівського типу з металогідридним катодом у пульсуючому режимі. Металогідридний катод забезпечував локальну інжекцію водню в активованому стані та впливав на здатність пеннінгівського розряду емітувати іони H^- у поздовжньому напрямку. Для стимуляції десорбції попередньо збудженого водню з гідриду металу до анода розряду підводили імпульс напруги (4,5 кВ, $\tau \approx 15$ мкс) на фоні постійної напруги 6 кВ. Отримано струм іонів H^- близько 0,2 мА.