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MODULATION OF NEGATIVELY CHARGED PARTICLE FLUX FROM PENNING DISCHARGE WITH METAL HYDRIDE CATHODE

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The features of modulation of negatively charged particle flux extracted along the magnetic field from Penning discharge with metal hydride cathode have been investigated. The separation of negative ions from coextracted electrons was performed by an electromagnetic filter with efficiency not worse than 90 %. It is shown that electrons in the extracted flow are deeply modulated with the frequency of the diocotron instability of the anode layer, while negative ions are not. An increase in the interelectrode distance and anode length resulted in a more pronounced expression of this effect due to the minimization of the influence of the magnetic field of the filter on the discharge.

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INTRODUCTION

Due to the neutralization efficiency, that remains acceptable at higher kinetic energy, negative hydrogen (H^-) ions are widely used for injection into high power proton accelerator facilities for fusion [1], and for production of medical radionuclides [2]. The initial beam of negative ions is usually produced by two well-known mechanisms: the process at the plasma surface boundary and the process in the plasma volume [3].

Cesium deposition on the plasma electrode surface is usually used in surface plasma sources that significant intensify the H^- beam [4]. But it causes cesium leakage to the acceleration zone leading to operational risks. In the second case, H^- ions are formed directly in the plasma volume by the mechanism of dissociative attachment of low-energy electrons to rovibrationally excited molecules of hydrogen. The current of H^- beam from volume sources keeps much low intensity, then from surface plasma sources, but they are more reliable and environmentally friendly (cesium free).

Source operation with metal hydride cathode is known to increase the production of H^- ions [5]. The stored hydrogen is chemically bounded and released in an atomic state at the required rate under the discharge current impact. Highly rovibrationally excited molecules H_2* are formed by the recombination of H-atoms at the metal hydride surface, which then can be easily converted to H^- by dissociative electron attachment [6].

Previously we reported about successful application of metal hydride cathode in Penning negative ion source [5]. The extraction of negatively charged particles are performed along the magnetic field followed by the separation of H^- ions by electromagnetic filter. But there are about 10% electrons in the registered H^- current despite the successful separation in general [7]. These are axial electrons, which are weakly affected the transverse component of magnetic field of the filter.

The purpose of this paper is to study the modulation of extracted current of negatively charged particles in order to find the way to improve separation performance.

1. EXPERIMENTAL SETUP

A schematic illustration of the experimental apparatus is shown in Fig. 1. The discharge cell consists of a water-cooled metal hydride cathode *1*, a tubular anode *4* and a copper cathode *5*, which are placed in an external uniform longitudinal magnetic field H_{zo0} = 0…0.1 T. The metal hydride cathode was produced from hydride-forming alloy $Zr_{50}V_{50}$ using the standard method of metal hydride preparation includes its melting, activation and filling with hydrogen. The hydrogen amount which is absorbed by hydride material was ~ 190 cm^3/g at atmospheric pressure and room temperature. Since the process of the alloy uptake with hydrogen is accompanied by the crystal lattice destruction, the obtained hydride powder was mixed with a cooper binder and then pressed in a disk 2 cm in diameter with the thickness of 0.4 cm.

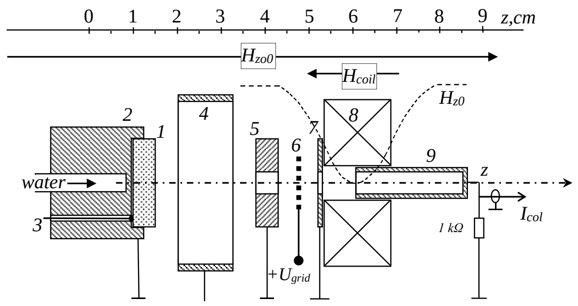

Fig. 1. The schematic illustration of the Penning type H^- ion source: 1 – metal hydride cathode; 2 – cathode-holder with water-cool; 3 – thermocouple; 4 – anode; 5 – copper cathode with an aperture; 6 – reflecting grid; 7 – electrons collector; 8 – filter magnetic coil; 9 – H^- ion collector; H_{zo0} – main axial Penning magnetic field (H_{zo0} = 0…0.1 T); H_{coil} – reverse magnetic field of the filter

Due to the water-cool of metal hydride its temperature was not exceed 20 ^{0}C, that much lower than the temperature of thermal destruction of hydride phases. Therefore, H_2* desorption is determined only by a discharge current and is provided mainly by ion-stimulated processes from the surface of metal hydride.

A flow of negatively charged particles including negative ions and electrons along with positive ions was registered along the external magnetic field through an aperture in the cathode 5. The separation of H^- ions was performed by electromagnetic filter. It includes 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} between the cathode 5 and the collector 9, so that the resulting field H_{z0} in the gap is enough to divert electrons on the collector 7. The required values of the field H_{z0} and grid potential in the filter were 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 discharge operation is ensured by positive potential U_d application to the anode. The cathodes have ground potential.

All studies were carried out only on hydrogen desorbed from metal hydride cathode under the ion current impact from discharge plasma without external gas injection at residual pressure of $2{\cdot}10^{-6}$ Torr.

2. RESULTS AND DISCUSSION

A voltage applied to the anode is concentrated in anode layer region of negative space charge, forming approximately radial component of electric field. The central plasma is almost field-free, where the electrons oscillate between cathode layers. The creation of H^- ions takes place near the metal hydride cathode followed by the ejection in longitudinal direction.

Previously we analyzed the behavior of H^- current depending on plasma electron temperature T_e [8]. The main conclusion was the more T_e, the closer electron reflects from the metal hydride cathode. But revealed in [9] existence of electrons groups with different energy leads to a discrepancy between the experimental data and the calculated ones. The groups of electrons with different energies appear due to heating on the instability of the anode layer.

The characteristic dependence of the oscillation frequency, measured on the anode with spectrum analyzer, on the magnetic field $1/f \sim H$ indicates on a diocotron type instability (Fig. 2). Oscillation amplitude A (in relative units) behaves non-linearly and is characterized by large values in the range of magnetic fields from 0.06 to 0.083 T.

The region to 0.05 T was not considered, since no sufficient yield of negative ions was observed here [5].

The study of H^- ion beam modulation was performed with an oscilloscope, connected to the H^- ion collector 9 (see Fig. 1) of the electromagnetic filter. The spectra were taken with oscilloscope in the spectrum analyser mode using Hanning method (Figs. 3, 4).

The figures represent the obtained results, where the change in the main harmonic of the signal was evaluated. The screenshots of the oscilloscope screen are given for the magnetic field, where the modulation suppression effect is the most efficient.

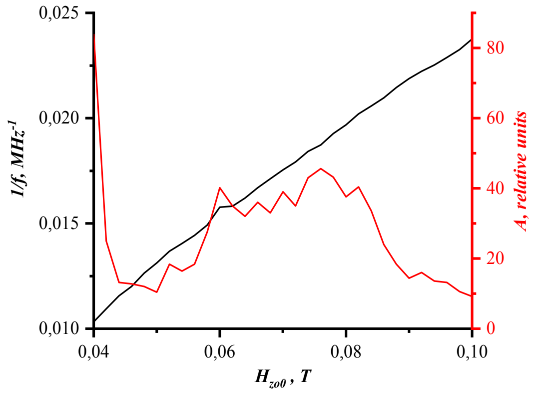

Fig. 2. The dependence of frequency and arbitrary amplitude of oscillation in anode layer on magnetic field at U_d = 5 kV, I_d = 0.8 mA, P = $5{\cdot}10^{-6}$ Torr

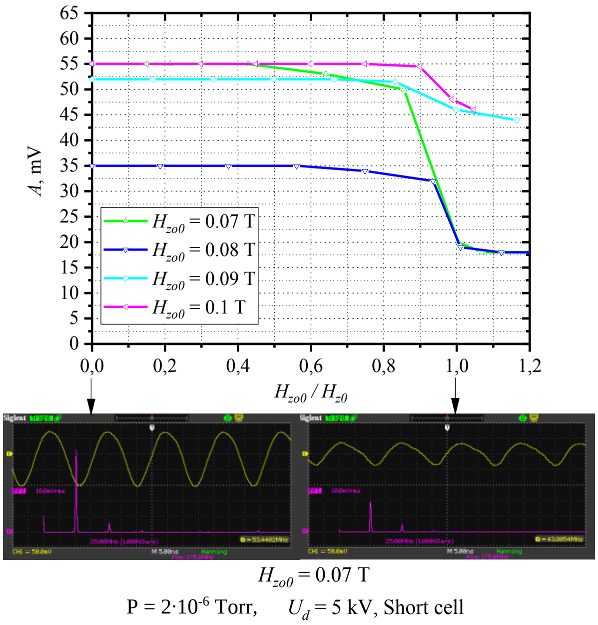

Fig. 3. The oscillograms and the dependence of arbitrary amplitude of oscillation of extracted negative current on H_{z00}/H_{z0} in case of short cell

When resulting magnetic field H_{z0} in the gap of electromagnetic filter is equal to the main axial Penning magnetic field H_{z00}, the axial electrons are diverted and do not fall on H^- ion collector [5]. So, a decrease of the oscillation amplitude in Fig. 3 can be associated with the modulation of the electron flow. Incomplete suppression of oscillations is due to the fact that a part of the near-axis electrons, which is weakly sensitive to the action of the transverse component of the magnetic field, passes to the H^- ion collector. According to [5], their part is about 10 % of the total number of electrons. However, the effects associated with the diffusion of electrons across the magnetic field, as well as possible electromagnetic pickups, are not taken into account here.

Nonetheless, one can also see the correlation between the intensity of oscillations in the anode layer and the suppression efficiency. The oscillation amplitude in the anode layer is non-linear (see Fig. 2) and possess large values for magnetic fields from 0.06

to 0.083 T. It is in this range the most pronounced effect of suppression of the intensity of oscillations is appeared.

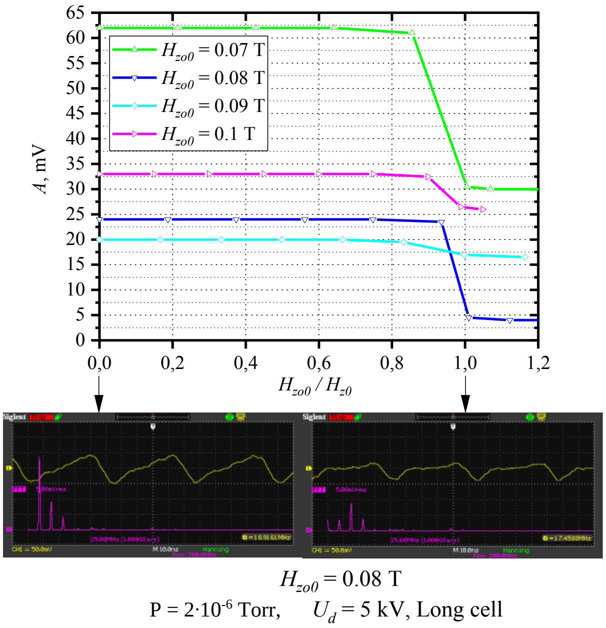

Fig. 4. The oscillograms and the dependence of arbitrary amplitude of oscillation of extracted negative current on H_{zo0} / H_{z0} in case of long cell

Increasing the distance between cathodes and anode from 0.4 to 1 cm makes the suppression effect clearer, obviously, due to the decrease of the influence of the filter on the discharge plasma.

CONCLUSIONS

Hydrogen desorption in activated state from metal hydride cathode, caused by ion bombardment of the surface, leads to intensification of H^- ions formation and ejection them in longitudinal direction together with electrons, which have got different energies due to heating on the instability of the anode layer. Thereby electrons in the extracted flow of negative particles are deeply modulated with the frequency of the diocotron instability of the anode layer, while negative ions are not. An increase in the interelectrode distance and anode length resulted in a more pronounced expression of this effect due to the minimization of the influence of the magnetic field of the filter on the discharge.

The effect of the modulation of extracted electron current can open the way for improving the separation performance.

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МОДУЛЯЦІЯ ПОТОКУ НЕГАТИВНО ЗАРЯДЖЕНИХ ЧАСТИНОК З РОЗРЯДУ ПЕНИНГА З МЕТАЛОГІДРИДНИМ КАТОДОМ

І. Середа, Я. Гречко, М. Азарєнков

Досліджено особливості модуляції потоку негативно заряджених частинок, витягнутих уздовж магнітного поля з розряду Пенінга з металогідридним катодом. Відділення негативних іонів від спільно витягнутих електронів проводилося електромагнітним фільтром з ефективністю не гірше, ніж 90 %. Показано, що електрони у вилученому потоці глибоко модулюються на частоті діокотронної нестабільності анодного шару, а негативні іони – ні. Збільшення міжелектродної відстані та довжини анода призвело до більшого вираження цього ефекту за рахунок мінімізації впливу електромагнітного фільтра на розряд.