SEPARATION OF NEGATIVE HYDROGEN IONS FROM PENNING DISCHARGE WITH METAL-HYDRIDE CATHODE

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In the paper we numerically investigate the separation of negative hydrogen ions extracted in the longitudinal direction from Penning discharge with a metal hydride cathode. For this purpose a cathode unit has been designed where the active element for H^- ions separation was electromagnetic filter. Basing on numerical solution of motion equations it was determined the trajectories of charged particles in the filter. A model that allows choosing the best external parameters for efficient separation of H^- ions and interpretation of subsequent experiments has been built. The experimental verification of the built model working ability was carried out.

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INTRODUCTION

The original dividing of the areas of hydrogen molecules H_2 excitation and H^- ions formation ensures the attractiveness of Penning discharge application as a source of negative ions with bulk generation [1]. The main mechanism of negative ions formation is dissociative attachment of thermal electron to vibration-excited hydrogen molecule H_2^*. Extraction of H^- ions is commonly carried out perpendicular to magnetic field [1, 2], but increase of beam intensity – by cesium vapor injection [3].

There is, however, another non-cesium way of enhancing the source brightness. It lies in the use of an active metal hydride cathode (MH-cathode) previously saturated with hydrogen. Hydrogen desorbed from the cathode is already in vibration-excited state H_2^*, and it injected to the place where the most number of thermal electrons contains: to the near-cathode region [4]. Thus, the efficiency of H^- ions formation by dissociative attachment mechanism increases.

On the other hand, MH-cathode applying sufficiently changes properties of Penning discharge. In particular, there is an additional operation mode in the high-voltage range, where emission properties of the discharge dramatically change. Namely, in the axial direction negative current starts extracted [5, 6]. Exactly this fact was the basis for the idea of negative hydrogen ions source creation with longitudinal extraction. The problem arisen here is the necessity of H^- ions separation from the total flux of particles emitted along the magnetic field. Considering the large difference in mass of a hydrogen ion and an electron it is conveniently to separate them by inhomogeneous magnetic field behind the passive cathode-reflector. And separation of positive ions H_2^+ is carry by electric field.

1. PROBLEM STATEMENT

To solve this problem it was made an cathode unit (Fig. 1). It consists of an anode (1), a copper passive cathode (2) and a magnetic filter which includes a grid (3), a coil of magnetic field (5), electrons current collector (4) and a collector of negative ions (6).

The passive copper cathode (2) has got an aperture in the center 0.5 cm in diameter for charged particles extraction.

The magnetic filter was set on the axis of the discharge behind the aperture in the passive cathode so, that all reverse magnetic field of the coil (5) was concentrated outside the discharge cell. For convenience the distance between the cathode (2), the grid (3), the electron and ion collectors (4 and 6) were the same and were 0.5 cm. Thus, the coil edge and the collector (6) were at the distance of 1.0 and 1.5 cm from the cathode edge respectively.

The cathode (2), the collectors (4 and 6) were under ground potential. The grid (3) was supplied by +3 kV for positive particles removing. The whole electrodes system was placed in external uniform longitudinal magnetic field with intensity could be changed in the range of $H_{zo0} = 0...1000$ Oe.

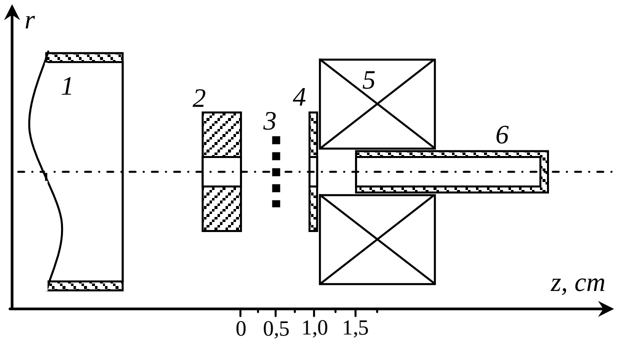

Fig. 1. The cathode unit: 1 – anode; 2 – copper passive cathode; 3 – grid; 4 – electron current collector; 5 – magnetic field coil; 6 – negative ion collector

The idea is to create reverse magnetic field in a gap between the cathode (2) and the collector (6) to deflect the electrons on the collector (4), but not impact on H^- ions to be registered by collector (6).

External magnetic field H_{zo0} and total field in the gap H_{z0} were chosen by analyzing the trajectories of electrons and H^- ions. Taking into account the electrodes configuration, which provides registration only axial group of particles, the equation of motion could be greatly simplified. So it could be considered the trajectory of charged particles only near the axis in an axially symmetric field [7]. The result is a paraxial trajectory equation in meridian plane $r = r(z)$:

$$\frac{d^2r}{dz^2} + \frac{1}{2}\frac{\phi_o'}{\phi_o}\frac{dr}{dz} - \frac{q}{8mc^2}\frac{rH_{z0}^2}{\phi_o}\left(1-\left(\frac{r_0^2 H_{zo0}}{r^2 H_{z0}}\right)^2\right) = 0.$$

Here $\varphi_o = \varphi(0, z)$ – the potential on the axis with respect to the point of the particle's birth $\varphi_{o0} = \varphi(0, z_0)$. (In our case, the potential of the point of particle birth (emitter potential) $\varphi_{o0} = 0$); $H_{z0} = H(0, z)$ – a magnetic field on the axis at an arbitrary point; $H_{zo0} = H(0, z_0)$ – magnetic field on the axis at the point z_0 – emitter point.

Equation (1) was obtained under the assumption of a uniform magnetic field (and do not depend on r) and in the case of slowly varying electric and magnetic fields (in the expansion in a Taylor series corresponding value allowed only the first term).

2. CALCULATION RESULTS

To solve the equation (1) it must be specified a nonuniform magnetic and electric fields in the investigated gap. The magnetic field profile in the equation (1) depends on two variables: $H_{zo0} = H(0, z_0)$ it is in our case external magnetic field on the axis without filter coil. $H_{z0} = H(0, z)$ it is no uniform magnetic field in the axis gap between the cathode and the ions collector, made by reversal switching of the coils. The parameter values H_{zo0} were fixed and were chosen at the level of 600, 800, and 1000 Oe basing on the device working conditions. The profiles H_{z0} and $\varphi_o = \varphi(0, z)$ were calculated in the program *femm 4.0* basing on the geometric dimensions of the cathode unit, the electrodes potential and the current flowing through the coil.

Solution of equation of paraxial trajectory (1) was carried out numerically by the Runge-Kutta fourth order with fixed step integration. The result of the numerical solution depend on the type of $r(z)$ – the radius of a particle position at a certain value of the longitudinal coordinate z in the gap cathode – collector. In our calculations, the coordinate z = 0.0 cm corresponds to the cathode end face, z = 1.5 cm – to the collector edge, and z = 1.75 cm – to the center of the coil created reversal magnetic field (see Fig. 1). These relationships are presented as graph forms in the Fig. 2. For convenience on these figures are given profiles of total magnetic field, the magnetic coil and the collector of charged particles. The position and size of the coil and the collector correspond to the figure scale.

One can see that the reversal magnetic field has a little effect on the trajectory of H^- ions, whereas, the electron trajectories are bent significantly and at the value of total magnetic field equal zero in the collector edge do not fall on it.

It should be noted that r coordinate of the electron on the collector edge (z = 1.5 cm) essentially depends on the initial value of the constant r_0, where r_0 – radius of electron entry in the gap. For example, at zero field on the collector edge and r_0 > 0.08 cm all the electrons are deflected and do not fall on the collector. Accordingly, electrons that are moving strictly along the axis of the tube 0.16 cm in diameter slightly deflected by the magnetic field and get into the collector. Estimates show that the current produced by these electrons around an order of magnitude lesser than the total incoming current at the collector. In other words, if the collector is get exclusively electron beam, the effect of reversing magnetic field will reduce its current in about 10 times.

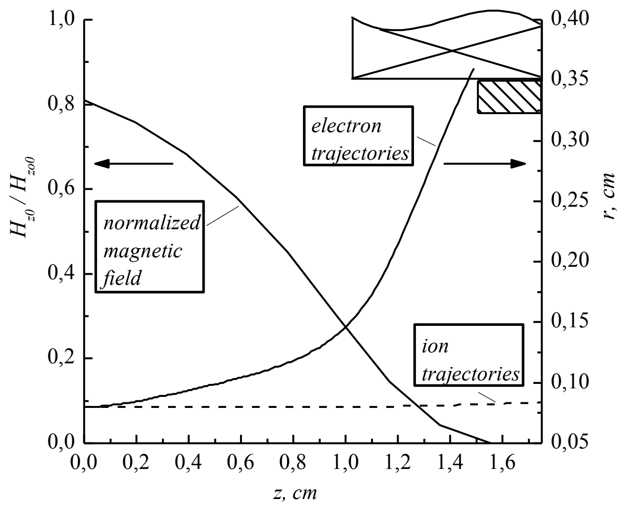

Fig. 2. The trajectories of electrons and ions as well as normalized profile of magnetic field in the gap cathode-collector

In the same time due to weak trajectory changing in the magnetic field ions will still fall on the collector regardless of the entry radius.

The model experimental verification was carried out by registering the electron beam in the nonuniform magnetic field generated by reversal switching of the two coils. For this an electron gun set on the axis of the system behind the anode (1) was applied. It created a cylindrical electron beam 1.2 cm in diameter with a current of 10 mA and with energy of 100 eV. Electron beam parameters were selected basing on the conditions of the experiment [5, 6]. The experimental results are shown in Fig. 3.

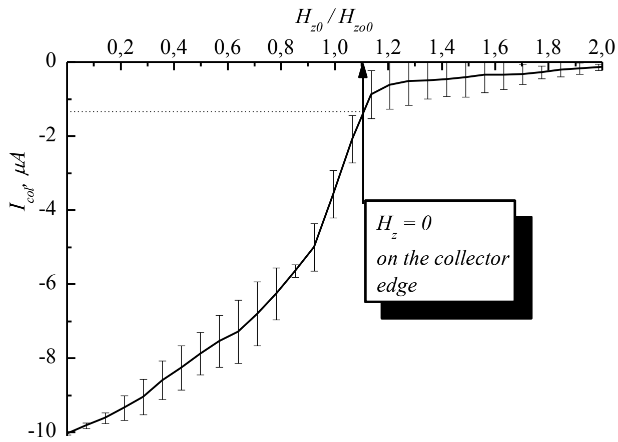

Fig. 3. The electron current depending on magnetic field in the coil center H_{z0} normalized to the value of external magnetic field H_{zo0} at $P = 5\cdot10^{-6}$ Torr

It should be noted that in the experiments the field value H_{z0} in the gap was calculated in the program *femm 4.0* based on the actual current supplied the coil. Therefore, in Fig. 4 parameter H_{z0} – it is a field in the center of the coil (coordinate z = 1.75 cm). To satisfy the condition of zero field in the collector edge (z = 1.5 cm) the normalized field should have a value of $H_{z0} / H_{zo0} = 1.1$.

Thus, it was obtained a satisfactory agreement between the experimental and calculated data. So the model could be considered as working and applied for the qualitative interpretation of following experiments.

CONCLUSIONS

As a result of numerous calculations, it was built a model that allows choosing the best external parameters for efficient separation of *H*-ions from the axial flow of charged particles. Experimental verification of the model was carried out by the axial electron beam attenuation in an organized magnetic field. Good coincidence between the experimental and calculated data showed the possibility of applying the model for the interpretation of following experiments.

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СЕПАРАЦИЯ ОТРИЦАТЕЛЬНЫХ ИОНОВ ВОДОРОДА ИЗ РАЗРЯДА ПЕННИНГА С МЕТАЛЛОГИДРИДНЫМ КАТОДОМ

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Численно исследуется сепарация отрицательных ионов водовода, извлекаемых в продольном направлении из разряда Пеннинга с металлогидридным катодом. С этой целью разработана конструкция катодного узла, активным элементом которого для сепарации ионов H^- является электромагнитный фильтр. На основании численного решения уравнения движения определены траектории заряженных частиц. Построена модель, позволяющая выбирать оптимальные внешние параметры для эффективной сепарации ионов H^- и интерпретации последующих экспериментов. Проведена экспериментальная проверка работоспособности построенной модели.

СЕПАРАЦІЯ НЕГАТИВНИХ ІОНІВ ВОДНЮ З РОЗРЯДУ ПЕННІНГА З МЕТАЛОГІДРИДНИМ КАТОДОМ

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Чисельно досліджується сепарація негативних іонів водню, видобутих у поздовжньому напрямку з розряду Пеннінга з металогідридним катодом. З цією метою розроблена конструкція катодного вузла, активним елементом якого для сепарації іонів H^- є електромагнітний фільтр. На базі чисельного рішення рівняння руху визначені траєкторії заряджених частинок. Побудована модель, що дозволяє вибирати оптимальні зовнішні параметри для ефективної сепарації іонів H^- і інтерпретації наступних експериментів. Проведено експериментальну перевірку працездатності побудованої моделі.