METHOD OF INCREASING THE LONGITUDNAL CURRENT OF H^- IONS FROM PIG WITH A METAL-HYDRIDE CATHODE

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The possibility of increasing the current of negative hydrogen ions extracted in the longitudinal direction from Penning discharge with a metal-hydride cathode by changing potentials at the discharge cathodes is investigated. An electromagnetic filter is used to separate negative ions from the extracted flux of charged particles. A significant correlation between the extracted total current and the current of negative ions from the cathode potential was found. The optimal parameters for the effective extraction of H^- ions are determined. The current of the H^- ion beam at a level of 10 μA was obtained.

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INTRODUCTION

H^- negative hydrogen ions have a high neutralization efficiency over a wide energy range [1], they are used both in solving the problem of controlled fusion [2], and in the production of a number of medical radionuclides for diagnostics and contact radiation therapy [2, 3].

The main requirements imposed on the H^- ions sources are its brightness and ecological purity. However, nowadays it is not possible to meet these two requirements in one device, since an increase in the efficiency of the source is achieved only by injection cesium vapor into it [4].

For environmentally friendly use, it is necessary to have cesium-free sources with H^- volume production [5]. The formation of negative ions in these sources occurs due to the dissociative thermal electrons attachment to vibrationally excited hydrogen molecules H_2^*, which are formed due to collisions with electrons energy of ≥ 50 eV [1, 6]. Therefore, these sources are double-chambered, which invariably entails H_2^* molecules loss and a decrease of the H^- ions production efficiency.

Moreover, due to a change in the discharge properties when a metal-hydride cathode is using, it opens the possibility for longitudinal extraction of negative ions [8, 9].

The original separation of regions with fast and slow electrons exists in a Penning discharge: in an anodic layer, electrons are heated to the necessary energy due to diocotron instability, and in a cathode region there is a large number of slow electrons obtained both from secondary emission processes and from reflection and scattering [7]. If one or both cathodes are made of metal-hydride, the H_2^* molecules are formed due to the activation of desorbed hydrogen directly at its surface [8]. This significantly increases the efficiency of ion production in the discharge volume. Moreover, due to a change in the discharge properties when a metal-hydride cathode is using, it opens the possibility for longitudinal extraction of negative ions [8, 9].

The purpose of this article is to investigate the possibility of increasing the current of negative hydrogen ions extracted in the longitudinal direction from Penning discharge (PIG) with metal-hydride cathode by changing the potentials at the discharge cathodes.

1. EXPERIMENTAL SETUP

A schematic diagram of PIG with a metal-hydride cathode and an electromagnetic filter is shown in Fig. 1.

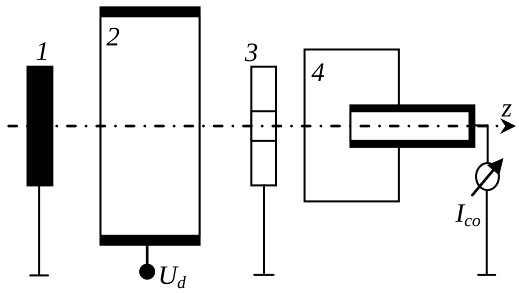

Fig. 1. The scheme of experiment: 1 – metal-hydride cathode; 2 – anode; 3 – cathode-reflector; 4 – electromagnetic filter

The discharge cell consisted of a water-cooled metal-hydride cathode 1, a tubular anode 2, and a copper cathode-reflector 3 with a central aperture. Behind the aperture of the cathode-reflector was an electromagnetic filter 4 for cutting off positive ions and electrons. The calculation and design of the filter are discussed in [10].

The metal-hydride cathode 1 had a disk shape of 5 thick and 20 mm in diameter. It was made by pressing a hydrogen-saturated powder $Zr_{50}V_{50}$ with a copper binder. The initial degree of hydrogen saturation was ~ 900 cm^3 under normal conditions. The metal-hydride cathode had water cooling to stabilize the desorption rate of hydrogen. Its temperature in the experiments did not exceed 20 ^{0}C, which is much lower than the decomposition temperature of the hydride phases. Therefore, H_2^* desorption was determined only by the discharge current and generally was provided by ion-stimulated processes on the surface of the metal-hydride [8].

It was possible to supply potentials to the discharge cathodes to study the possibility of increasing the

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negative ions current. The range of variation of the supplied potentials was(0 ± 250) V.

2. RESULTS AND DISCUSSION

Fig. 2 demonstrates the operation of the PIG with a metal-hydride cathode and an electromagnetic filter as an axial source of negative hydrogen ions. This figure shows the dependence of collector current I_{coll} on discharge voltage U_d with the electromagnetic filter turned off and on.

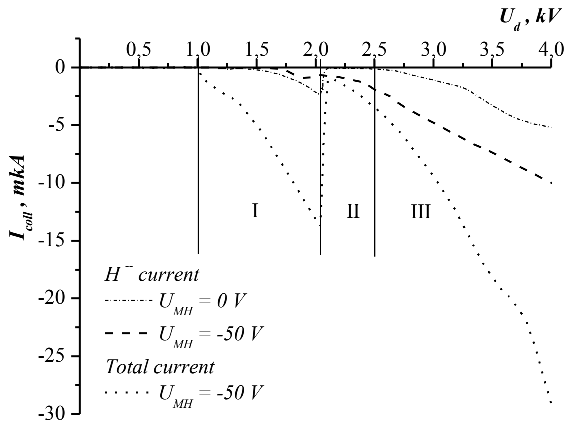

Fig. 2. The dependence of collector current I_{coll} on discharge voltage U_d (H_z = 1000 Oe, $p = 3.5{\cdot}10^{-6}$ Torr)

Total collector current includes positive ions current, electrons current and H^- negative hydrogen ions current. The Penning discharge operates in one of three modes, depending on anode voltage, when positive ions or electrons predominate in the axially-directed current [8, 9].

In the mode I (U_d = 1…2 *kV*) the negative current is more than 10 times higher than the current with electromagnetic filter is switched on. Basically it's an electron current successfully suppressed by a magnetic filter.

Mode II ($U_d \geq 2$ *kV*) is characterized by the fact that ions predominate in the outflow current [9] against the symmetrical electrical inclusion, when both cathodes were grounded. The supply of negative bias at the metal-hydride cathode leads to the fact that the total current registered by the collector always has negative values, i.e. positive ions in the outflow cannot compensate the negative particles.

And, finally, in the mode III ($U_d > 2.5$ *kV*) a high negative current appears again. As noted previously [8, 9], the mode III is a consequence of the use of the metal-hydride cathode.

The shape of the curve for the ion current H^- with the filter applied repeats the shape of the total current, which agrees with the previous works [10, 11]. However, the values of the extracted current of negative ions depend strongly on the magnitude of the electric bias.

Fig. 3 shows the behavior of the total current on the collector (electromagnetic filter is turned off) and the ion current H^- with the filter turned on, depending on the magnitude of the negative bias on the metal-hydride cathode.

We can see, that the total, axially-directed current grows with negative bias on the metal-hydride cathode. This total current consists predominantly of electrons, which, under the action of an electric field, are pushed out of the cell volume toward the cathode-reflector. An increase in the ejection field leads to an increase in the extracted current, which agrees with the results of other authors' experiments [7].

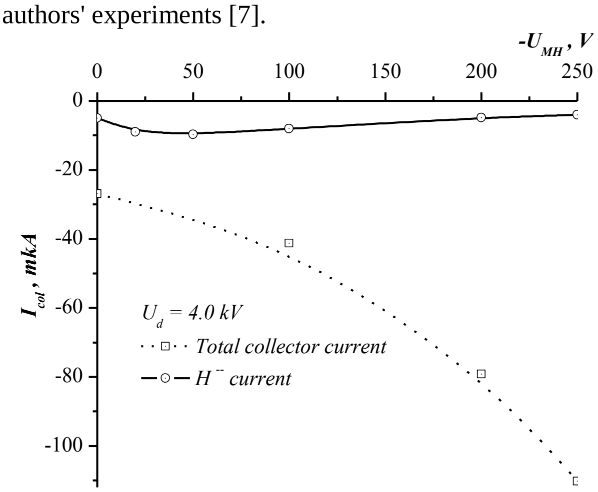

Fig. 3. The dependence of collector current I_{coll} on negative bias on the MH-cathode (H_z = 1000 Oe, $p = 3.5{\cdot}10^{-6}$ Torr)

On the other hand, a double increase in the current of negative ions with the filter turned on is observed only within the limits of the change in the potential on the metal-hydride cathode to -50 V. Further increase in the magnitude of the negative electric bias on the metal-hydride cathode leads to a decrease in the current of negative ions to previous values and lower, despite on a significant increase in the total current of charged particles extracted in the longitudinal direction. This is due to the fact that the region of rotation of the electron trajectories is moved away from the surface of the metal-hydride cathode and the efficiency of the formation of H^- ions decreases by the mechanism of the dissociative attachment of slow electrons to the desorbed excited hydrogen molecules H_2^*.

The supply of a positive potential to the cathode-reflector leads to directly opposite results (Fig. 4). With increasing of the electric bias, the current of negative ions decreases together with the total outgoing longitudinal current.

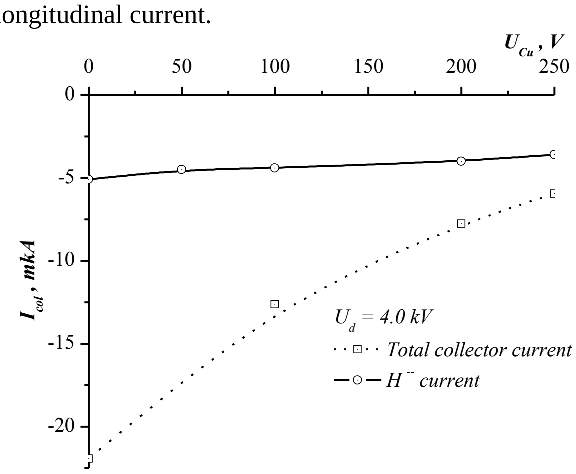

Fig. 4. The dependence of collector current I_{coll} on positive bias on the cathode-reflector (H_z = 1000 Oe, $p = 3.5{\cdot}10^{-6}$ Torr)

When electric bias is applied to the cathodes, as in the case of the previous experiments [11], the current of the H^- ions weakly depends on the external magnetic field and increases together with the discharge voltage.

CONCLUSIONS

The paper shows the possibility of increasing the current of negative hydrogen ions extracted in the longitudinal direction from the Penning discharge with a metal-hydride cathode. It is established that the maximum value of the current of extracted in the longitudinal direction H^- ions is achieved by applying a negative bias to the metal-hydride cathode in the range from 20 to 50 V. Desorption of hydrogen from the metal-hydride cathode in the form of vibrationally excited H_2^* molecules leads to intense formation of H^- ions. The large mean free path of the ions H^- provides their unimpeded escape beyond the cell and the formation of an axial flow of charged particles in the longitudinal direction. Higher potentials move the region of rotation of the electron trajectories from the surface of the metal-hydride cathode and the efficiency of the formation of H^- ions decreases.

The supply of a positive potential to the cathode-reflector does not lead to any significant result.

The obtained current of negative hydrogen ions at the level of 10 μA at a discharge current of 1 mA and a discharge voltage of 4 kV can be interesting for high-vacuum devices in which it is required to inject continuous-type beams.

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УВЕЛИЧЕНИЕ ПРОДОЛЬНОГО ТОКА ИОНОВ H^- ИЗ РАЗРЯДА ПЕННИНГА С МЕТАЛЛОГИДРИДНЫМ КАТОДОМ

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Исследуется возможность увеличения тока отрицательных ионов водорода, извлекаемых в продольном направлении из разряда Пеннинга с металлогидридным катодом, путем изменения потенциалов на катодах разряда. Для сепарации отрицательных ионов из извлекаемого потока заряженных частиц применяется электромагнитный фильтр. Обнаружена существенная корреляция извлекаемого общего тока и тока отрицательных ионов от потенциала катодов. Определены оптимальные параметры для эффективного извлечения ионов H^-. Получен ток пучка ионов H^- на уровне 10 мкА.

ПІДВИЩЕННЯ ПОЗДОВЖНЬОГО СТРУМУ ІОНІВ H^- З РОЗРЯДУ ПЕНІНГА З МЕТАЛОГІДРИДНИМ КАТОДОМ

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Досліджується можливість збільшення струму негативних іонів водню, видобутих у поздовжньому напрямку з розряду Пенінга з металогідридним катодом шляхом зміни потенціалів на катодах розряду. Для сепарації негативних іонів, що витягаються з потоку заряджених частинок, застосовується електромагнітний фільтр. Виявлена суттєва кореляція загального струму і струму негативних іонів від потенціалу катодів. Визначено оптимальні параметри для ефективного вилучення іонів H^-. Отримано струм пучка іонів H^- на рівні 10 мкА.