NEW IN DEVELOPMENT OF NEGATIVE HYDROGEN ION SOURCE WITH COMBINED DISCHARGE

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The presented work shows a progress in development of the cesiated negative hydrogen ion source with combined discharge. The dependence of H^- ion beam current on power introduced into the discharge is shown to have a saturation, which enables optimization of the power value. As well, nonlinear behavior is exhibited by the dependence of the beam current on anode hole size. One more essential parameter is the accompanying working gas flow from the source anode to the chamber. Further optimization of extracting system design and method of working gas supply can provide additional improvement of operation characteristics of the source.

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INTRODUCTION

Investigation of the negative ion sources have a long story [1, 2]. For different applications there are different requirements for particle source, so that wide range of the devices exists. In negative hydrogen ion sources different mechanisms of ion formation [2-5] are used. We proposed in [6] and reported in [7, 8] the peculiarities of negative particle cesiated source of our design. Now we describe the last results in advances of the source.

As we reported earlier, the source enables formation of the stream of negatively charged particles with high brightness in energy range up to several tens kilovolt and axially-symmetric beam profile. However, the beam divergence angle remained very wide, which resulted in significant loss of the beam current at the walls of transport section. The research task consisted in optimization of ion-optical extracting system of the source aimed to formation of the beam with limited spread, and in comparison of characteristics of extracted negative charged particles beam at different power introduced into the discharge.

1. EXPERIMENTAL SETUP

The experimental setup was described in detail in [6-8]. The setup includes particle beam source and diagnostic tools. The residual pressure is 3×10^{-5} Torr. The negative charged particles source has the composite anode electrode 1 mm longer than before. Fig. 1 shows ion optics system of the source. The anode assembly 1 has replaceable insert with anode hole. Now we make emission hole with 3.5 mm diameter. It is 0.5 mm less than extractor diameter in [8]. The discharge in the source was ignited in pulse-periodical regime. For that purpose, voltages from respective pulsed power supply units were applied with 1…3 Hz repetition rate to hydrogen supply valve and electrodes of the source. During the discharge glow, cesium was emerged from cesium dichromate tablets located inside the source. Cesium was deposited onto the anode and promoted creation of hydrogen negative ions in vicinity of emission slit. For extraction and acceleration of hydrogen negative ions, up to 10 kV voltage was applied between the source anode and extracting electrode with 4 mm aperture diameter located at 2 mm distance from the anode. The beam was detected by means of collectors, which were modernized, as compared to those used in [7, 8]. Signals from the collectors were supplied to oscilloscope input, which registered current values of negatively charged particles. As well as in previous researches, two different schemes of the beam detection were used. In the first one the beam current was detected at 50 cm distance from the source by means of collector having 10 cm diameter [6]. At that, portion of the beam propagating inside a cone with about 12^0 angle was detected. In the second scheme multi-collector electrode [7, 8] with added system of two parallel slits was used, which promoted improved separation of hydrogen negative ion beam with the use of transverse magnetic field.

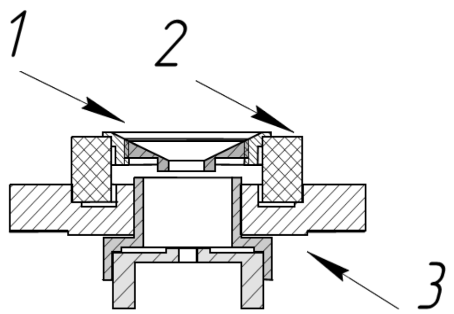


Fig. 1. Scheme of the ion optics system of the source: 1 – composite anode; 2 – insulator; 3 – composite cathode

Combined modernized collector for measurements of angular distribution of the beam current, as well as total one, is shown in Fig. 2. It differs from previously used one by presence of additional electrode 9. The electrode is composed of two parallel plates separated by 3 cm spacing. Two slits are cut out in them, each having 1 cm width, which enable separation of long stripe from the beam of charged particles. With magnetic field being turned on and varied, such arrangement provides better separation of electron stream from negative ion flow. At that, flows of the particles come to surfaces of the collectors 1-5 limited by the slits of additional electrode. By values of these currents and known areas of the surfaces, current density values onto each collector are determined, and total current onto each collector is calculated, as well as total current into the whole beam propagation angle embraced by the collector.

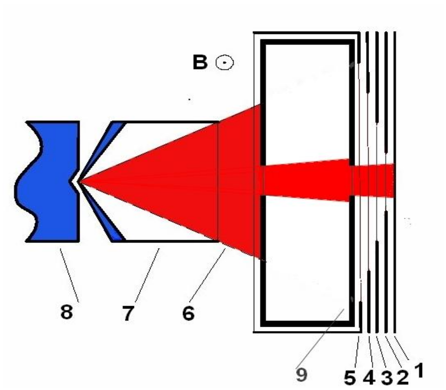


Fig. 2. Scheme of hydrogen negative ion beam current measurement at 8 cm distance from the source aperture: 1-5) collectors for measurements of the beam current components; 6) hydrogen negative ion beam; 7) extracting electrode of the source; 8) anode of the source; 9) additional electrode with two parallel slits

2. EXPERIMENTAL RESULTS

It should be noted that shape change of the anode electrode in the source resulted in certain decrease of total output current of negatively charged particles, as well as hydrogen negative ion one. However, improvement of electric breakdown strength of extracting gap became an undoubted advantage of this upgrade. As a result, the source quickly comes to operation regime without time loss to training for establishing work regime of the current extraction. Kinetics of the discharge parameters, as well as those of extracted current onto central electrode in the measurement scheme presented in Fig. 2 were studied by means of oscilloscope. Resulted oscillograms are presented below in Fig. 3. Oscillograms of the beam current are obtained both at zero magnetic field when the beam was composed of electrons and negative ions, and at transverse magnetic field of 35 Gs strength when resulted current onto the collector was due to hydrogen negative ions. Although the oscillograms do not show essential noise component, one can see that the traces have finite thickness. On a basis of obtained results, one can estimate the noise component of the discharge voltage is about 20 V. It should definitely lead to spread of the energy value in the beam. Additional contribution to the beam non-monochromaticity can be provided by existence of different ways of negative ion formation. Among those ways, the principal ones produce ions formed in recharging processes at the cathode surface, ions formed in the plasma volume, and ions formed at the anode surface. Current of the first group of ions is probably small enough since these ions quickly recombine at their propagation through the dense plasma layers. By estimations, free run path in such plasma does not exceed a couple of one tens fractions of millimeter.

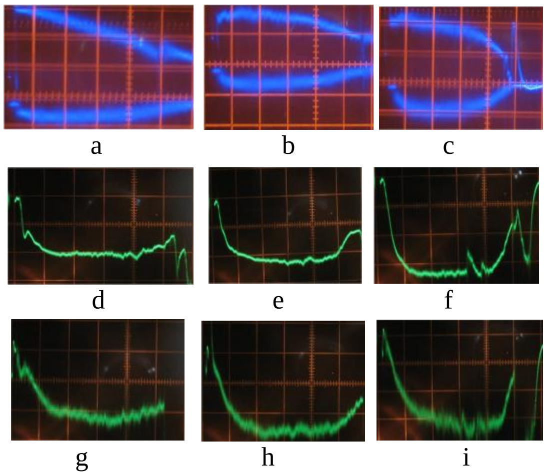
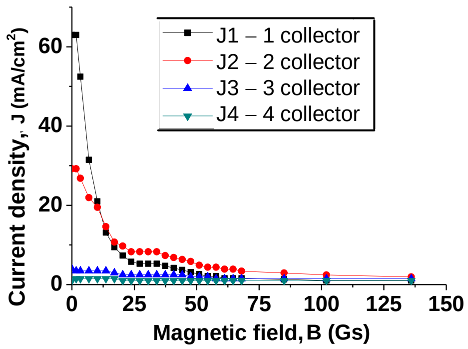


Fig. 3. Oscillograms of the discharge parameters of the source of negatively charged particles (a-c), and current values onto central electrode of modernized collector at turned off (d-f), and on (g-i) transverse magnetic field. (a-c) the top trace represents the discharge voltage, 50 V/div (a), 100 V/div (b,c); (a-c) the bottom trace represents the discharge current, a) 50 A/div (a), 100 A/div (b,c); (d-f) current onto the first collector at zero magnetic field, 100 mA/div; (g-i) current onto the first collector at magnetic field strength 35 Gs, 10 mA/div. The discharge voltage is 100 V (a,d,g), 120 V (b,e,h), and 150 V (c,f,i)

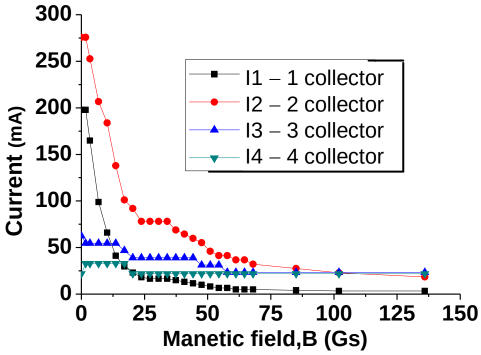
The most concentrated portion of ions of the second group is located in the near-anode region in the plasma with potential close to the anode one. With a presence of ion formation at the surface, contribution of this group to total negative ion beam current is small [5]. The most essential contribution is given by a group of negative ions formed by recharging of positive ions at the anode surface. Particularly, authors of [3] came to conclusion that resulted outcome of hydrogen negative ions due to recharging process reaches 80 %. Ions of the second and the third groups should compose basic portion of negative ion beam at output aperture of the source. Following from said above, one can expect that the main spread of the energy value will be close to 20 eV.

The next Fig. 4 exhibits dependencies of current density and the total current values onto the collector lamella shown in Fig. 2 obtained at the measurements with magnetic field strength variations after the calculations taking into account lamella area values. The measurements were performed at 30 A discharge current and 100 V discharge voltage (3 kW pulsed power). One can see from the results that at zero magnetic field strength maximum electron current is observed at central electrode. Increase of transverse field up to about 30 Gs results in plateau appearance at the plots. We suppose that it corresponds to practically total deflection of electron streams and proceeding to the measurement of negative ion current value. Already at 20 Gs field strength, Larmour radius of electron possessing 10 keV energy is 17 cm, which will deflect the stream at 8 cm distance for more than one centimeter that should be sufficient for almost complete cut off under experimental conditions given in Fig. 4. It is in a good agreement with the experimental results. Curiously, the current density to the nearest periphery electrode is even slightly higher than that onto the central one.

Considering the total current onto each electrode, one of the highest values of about 80 mA comes to the first periphery electrode. Current of just 20 mA comes to the central electrode (14^0propagation angle). Also one can see that the current with sum value of just about 50 mA comes to all other periphery electrodes. That is, major portion of negative ion current propagates inside relatively small angle. As one can see from the plots in Fig. 4,b, with this particular power introduced into the discharge the overall negative ion current is about 150 mA.



a



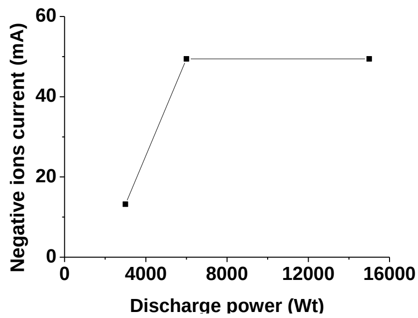
b

Fig. 4. Dependence of current density onto collectors on magnetic field strength. The discharge current is 30 A (a); Plot of averaged total current onto lamella obtained by multiplying the current density by each lamella area (b)

One can see at the plot that plateau section occupies relatively small range of magnetic field strength. The last may be due to appearance of negative space charge in the beam transport section with sequential locking of increasing number of electrons thus preventing their quick escaping onto the walls. As well, it may be due to penetration of already strong enough magnetic field to a section of the beam extraction from the source. The last effect will change the extraction conditions, which should obligatory influence the extracted current value. All said above gives evidence to necessity of replacement of the beam component analysis system for excluding the analyzer influence on the source.

The next Fig. 5 shows dependencies of the current of extracted hydrogen negative ions at extracting voltage of 10 kV to central electrode of combined collector (14^0propagation angle) and to the electrode of remote collector (12^0propagation angle) on power introduced into the source discharge.

As one can see, at increase of the discharge power, negative ion beam current tends to saturation that is probably due to an increase of the plasma concentration at the source periphery, which in turn leads to increase of a rate of negative ion decomposition in processes of collisions with the plasma particles. The dependencies of current values onto near and remote collectors exhibit similar behavior. However, one can note that the current to remote collector is essentially lower than that to near one, although propagation angles at that are of about the same values. Possible reason of such behavior is due to decomposition of negative ion particles in collisions with neutral particles of accompanying gas in the beam transport section.



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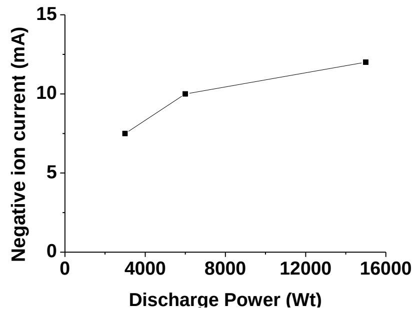

b

Fig. 5 Dependencies of total negative ion current with 14^0 propagation angle at 8 cm distance from the source aperture (a) and hydrogen negative ion current with 12^0 propagation angle at 50 cm distance from the source (b) on power introduced into the discharge

Peculiarity of negative ion beam formation in the source with emission slit having 3.5 mm diameter, as compared to one with the slit having 4 mm diameter is exhibited in Fig. 6. One can see that in the source with 3.5 mm emission aperture negative ion beam is formed mainly into essentially smaller angle. At that, radial distribution is uniform. It implies essential advantage of this version of the source at its combined operation with focusing device. As one can see from the figure, current density of electron beam has maximum value in the center and rapidly decreases towards the periphery.

Fig. 7 presents dependence of negative ion beam current onto remote collector from emission slit aperture diameter. One can see that the emission slit surface increase results in the growth of negative ion current from the source. At the same time, increase of emission slit surface leads to significant deterioration of electric strength of the source extracting gap. The source having 3.5 mm emission aperture diameter seems to be a reasonable compromise.

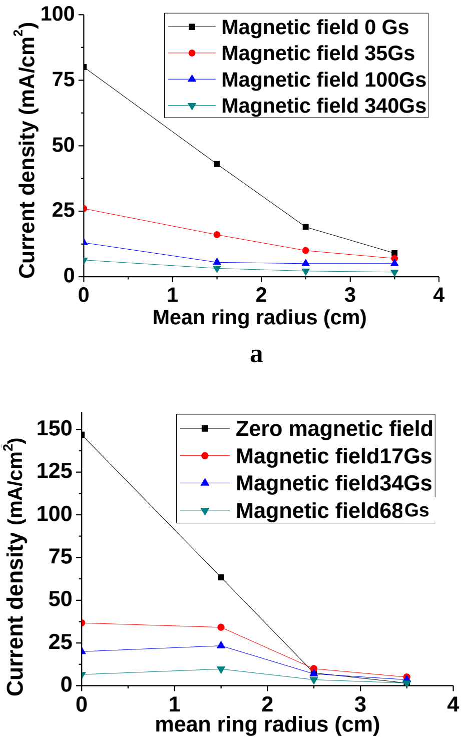

Fig. 6. Distributions of negative hydrogen ion beam current density over the rings of combined collector for different magnetic field strength and emission slit aperture 4 mm (a) and 3.5 mm (b). Pulsed discharge power is 15 kW

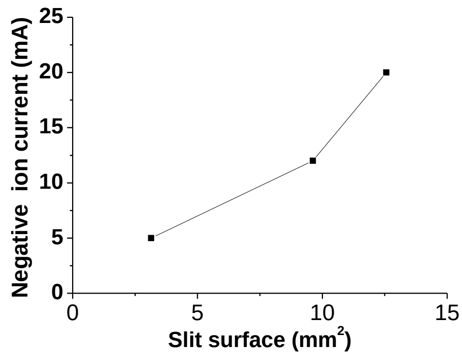

Fig. 7. Dependence of current onto remote collector from the source with anode holes of 2, 3.5, and 4 mm diameter on output slit surface. Pulsed discharge power is 15 kW

CONCLUSIONS

Thus, improvement of ion-optical system of the source requires, as a part, finding a compromise between retaining sufficient electric strength of the gap between the system and extracting electrodes, and reaching maximum possible value of extracted beam current. In case of our source and extracting voltage of an order of 10 kV such compromise may be provided by a hole having 3.5 mm diameter. The researches have also shown existence of saturation in dependence of the current of extracted negative ions on power introduced into the discharge. One of the ways of the design improvement can be solving the problem of negative ion loss at accompanying working gas flow. At the use of proposed source only as one of hydrogen negative ions, considerable increase of magnetic field for deflecting electrons may also result in deterioration of the conditions for H^- ion beam extraction. The optimum magnetic field strength may be one of 20…40 Gs value.

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ПРОГРЕСС В РАЗРАБОТКЕ ИСТОЧНИКА ОТРИЦАТЕЛЬНЫХ ИОНОВ ВОДОРОДА С КОМБИНИРОВАННЫМ РАЗРЯДОМ

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Показан прогресс в разработке источника отрицательных ионов водорода с комбинированным разрядом и цезием. Продемонстрирована зависимость тока отрицательно заряженных частиц от мощности, вкладываемой в разряд, и размера анодного отверстия. Зависимость тока пучка от вкладываемой в разряд мощности имеет насыщение, что позволяет оптимизировать этот параметр. Также нелинейный характер имеет зависимость от размера анодного отверстия. Ещё одним существенным фактором выступает сопутствующая струя рабочего газа, выходящая через анод источника в камеру. Дальнейшая оптимизация конструкции извлекающей системы и метода подачи рабочего газа может дополнительно повысить эксплуатационные характеристики источника.

ПОДАЛЬША РОЗРОБКА ДЖЕРЕЛА ВІД'ЄМНО ЗАРЯДЖЕНИХ ІОНІВ ВОДНЮ З КОМБІНОВАНИМ РОЗРЯДОМ

А. Добровольський, В. Горецький, В. Баженов

Показано прогрес у розробці джерела від'ємно заряджених іонів водню з комбінованим розрядом та цезієм. Продемонстрована наявність залежності струму від'ємно заряджених частинок від потужності, що вкладається в розряд, та розміру анодного отвору. Залежність струму пучка від потужності, що вкладається до розряду, має насичення, що дозволяє оптимізувати цей параметр. Також нелінійний характер має залежність від розміру анодного отвору. Ще одним суттєвим фактором виступає супутній струмінь робочого газу, що виходить крізь анод джерела до камери. Подальша оптимізація конструкції формуючої системи та методу постачання робочого газу може додатково підвищити експлуатаційні характеристики джерела.