DEVELOPMENT OF NEGATIVE ION SOURCE WITH COMBINED DISCHARGE

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The results of investigation of emission productivity of negative particles source with combined discharge are presented. A cylindrical beam of negative hydrogen ions with density about 5 A/cm^2 on source emission aperture is obtained. The full beam current values are up to 200 mA for negative hydrogen ions and up to 1.5 A for electrons with high divergence after source. The source has simple design and produces stable discharge with low level of oscillation.

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INTRODUCTION

Researches devoted to creation of hydrogen negative ion sources continue for several last decades [1]. These sources are widely used in physical experiments on controlled fusion and in some practical applications, such as neutron generators for medicine. The main attention of the researches is now drawn to development of powerful sources capable of generation of pulsed current with values about tens kA. However, the necessity in improvement of characteristics of moderate power sources still remains. The main efforts are directed to improvement of the beam emittance and the source economy. The present work is targeted to investigation of emission features of hydrogen negative ions or electron source of cylindrical beam operating in pulse-periodical mode with combined discharge.

1. APPROACH

Early we present the investigation of productivity of two variants of negative particles source – the first with a discharge in crossed fields only, and the second with additional hollow cathode type discharge. It was shown that presence of additional discharge significantly improves emission capability of the source [2]. From a source with combined discharge we register negative ion current about 5 mA at distance of 50 cm from the source by collector with 10 cm diameter. Here we present results of investigations of emission capability of advanced model of the source with combined discharge.
In design of our source we use experience of other authors [1, 3-7]. The main features of the source were described in [2]. Here we made the minor changes in discharge chamber design and changed the emission hole diameter. We explain increasing of negative ion current by influence of the second discharge. So in advanced model of the source we improve exchange capability between discharges chambers. Also, we increase emission of the source as a whole.

2. EXPERIMENTAL SETUP

Experimental setup consisted from studied gas discharge based H$^-$ ion source placed in vacuum chamber at pressure of $3{\cdot}10^{-5}$ Torr. The discharge was ignited after hydrogen supply to the source channel by means of pulsed valve. Cesium adding to the discharge was done by its extraction from cesium dichromate tablets during the source heating by electric discharge. Hydrogen supply valve and the source electrodes were powered by pulsed electric supply modules. High voltage power source of VS-50-50 type was used for the beam extraction and acceleration up to more than 10 keV energy. The beam was investigated by means of collectors described below. Signal from the collectors was supplied to oscilloscope input for determining current values of negatively charged particle beam. Main task of the investigations was determining the value of extracted H$^-$ ion beam current immediately at output aperture of the source. Besides, transport characteristics of obtained beams were studied. Due to that, two setups for determining the beam parameters were used.

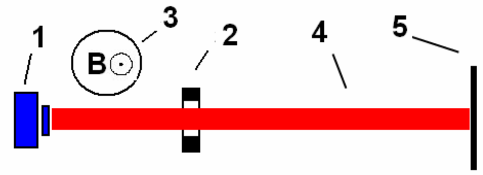

Fig. 1. Scheme of H$^-$ion beam current measurement at 50 cm distance from the source: 1 – source of H$^-$ions; 2 – magnetic shield; 3 – electromagnet poles; 4 – beam of H$^-$ ions; 5 – collector for the current measurement

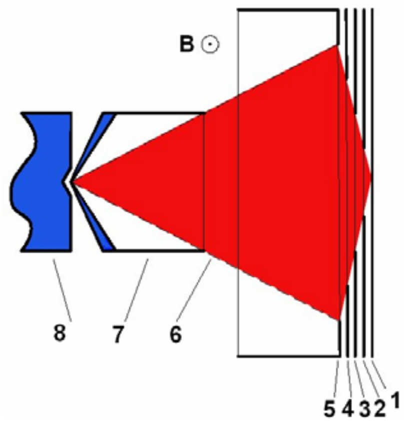

Fig. 2. Scheme of hydrogen negative ion beam current measurement at 8 cm distance from the source aperture: 1-5 – collectors for measurement of the beam current components; 6 – beam of hydrogen negative ions; 7 – extracting electrode of the source; 8 – anode of the source

The first setup for measurements of negative particle beam parameters at 50 cm distance from the source is shown schematically in Fig. 1. The beam current was measured by collector having 10 cm diameter, which determined the value corresponding to beam propagation within a cone having angle of about 12°.

Fig. 2 exhibits scheme of measurements of the beam parameters at 8 cm distance from output aperture of the source. Measuring device in this case consisted from 5 collectors. The first collector was bulk metal plate. The second, third, fourth and fifth ones were apertures with diameters of 2, 4, 6 and 8 cm, respectively.

The fifth collector was limited by a cylinder with equal potential having 10 cm diameter and 4 cm length.

At that, both total current of negatively charged particles including electrons, and H^- ion beam current could be measured. For separation of the particles, weak transverse magnetic field could be applied in vicinity of emission slit, which deflected electron flow to electromagnet poles.

The source exterior is shown in Fig. 3. The source was assembled between two flanges separated by isolator. The right side flange was mounted to vacuum chamber of the setup. Cathode system of the source was mounted at the left side flange. One can see electric power supply connectors and gas feed tube at external side of the flange. The right side flange was at ground potential. It held the elements of extracting system. The left side flange with the source cabinet in operation regime was at negative potential of about 10 kV.

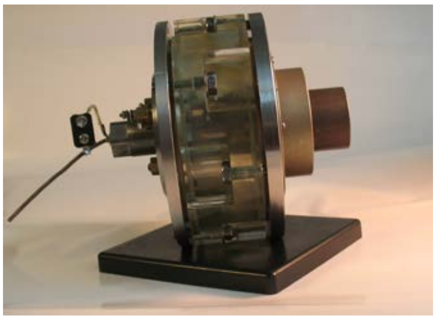

Fig. 3. Picture of negative ion source

One can understand operation principle of the source by consideration of its schematic drawing in Fig. 4.

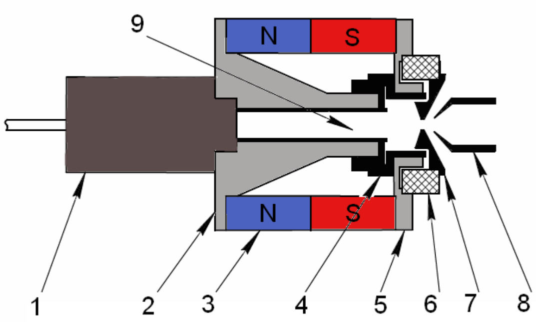

Fig. 4. Schematic drawing of H^- ion source

Number 1 denotes gas valve for hydrogen feed. The feed was done in pulsed mode 1.5 ms prior to the source discharge ignition. 2 and 5 are steel magnetic cores, which together with ring-shaped magnet 3 served for creation of magnetic field with about 1 kGs strength in the gap between anode 7 and cathode 4. It enabled ignition in this gap the discharge with crossed electric and magnetic field. The anode was separated from the cathode by ceramic isolator 6. Emission hole with 4 mm diameter was located in anode insert made of molybdenum in washer 7. Elements from 1 to 7 were mounted at external flange. Extracting electrode 8 was assembled on the front flange. Accelerating potential was applied to electrode of the anode 7 relatively to grounded electrode 8. As it was shown by the experiments, in chamber 9 at voltage supply to electrodes 4 and 7 additional discharge was ignited, which influenced essentially on emission features of the source. The discharge glowed in the cathode electrode cavity. We consider it as one of hollow cathode type [2]. Thus, two types of the discharges coexist in the source. These are hollow cathode discharge located inside the source, and the discharge in crossed fields near emission slit.

3. EXPERIMENTAL RESULTS

Two types of negatively charged particles – electrons and negative ions are extracted from the source with hydrogen as working gas. Taking into account considerable difference in masses of the particles, one can easily separate their flows by means of magnetic field. Behavior of the current value at magnetic field strength variation enables conclusion about portion of H^- current in the beam, and determination of possibility of the source use for production of H^- ion beams.

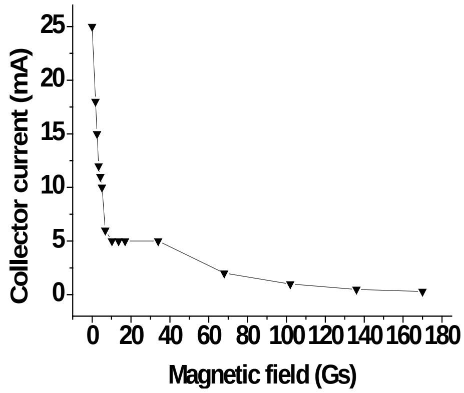

Fig. 5. Dependence of current of negatively charged particles to remote collector on magnetic field strength

Earlier in [2] measurements of current on collector with 10 cm diameter located at 50 cm distance from the source (cone with 12° angle) were performed. Plot of dependencies of negative particle current to the collector on magnetic field strength is presented in Fig. 5. One can see that at the field strength higher than 10 Gs the dependencies become weakly exhibited. This was considered as complete electron beam deflection. At that, current of heavy negatively charged particles flows to the collector. In our case these particles can be only hydrogen negative ions. The measurements have shown that the current of hydrogen negative ions is 5 mA. At that, emission slit had 2 mm diameter. In subsequent experiments, with emission slit diameter increase to 4 mm, we succeeded in enhancement of H^- ion current value at remote collector up to 20 mA. For determining peculiarities of negative particle flow from the source, collector shown in Fig. 2 was used. It enabled both measurement of total current from the source, and determining angular distribution of the current density.

Fig. 6 shows the total current corresponding to overall beam propagation cone (total beam current) depending on a deflecting magnetic field strength.

One can see similarity with behavior shown in Fig. 7. Particularly, sharp maximum of the current at zero magnetic field changes to slow decrease of current on collector with magnetic field strength growth. How-

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ever, unlike the case of previous plot, one can’t see sharp bend of the curve, and visible decrease of the current is observed only at the field strength of about 100 Gs, which is essentially bigger than in previous case.

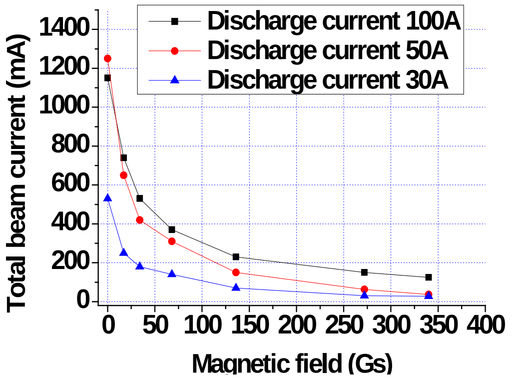

Fig. 6. Total current of negatively charged particles of the beam on collectors 1-4 (see Fig. 2) depending on magnetic field strength for three different values of discharge current in the source

It is explained by fact that at short distance larger deflection angle of the beam electrons is required, as compared to that at long distance. And this requires respective magnetic field strength increase. Namely, at the field of about 150 Gs, Larmor radius of electrons having 10 keV energy becomes equal to 4 cm, which prevents their coming to collectors 1-4. Thus, one can expect that in such case we measure only H^- ion current value. One can see that at discharge current of 100 A negative ion current value may exceed 200 mA. But this is a value for the current which propagates within cone having angle of about 50°. As well, one can see that the discharge current decrease, that is the decrease of supplied power, causes diminishing of extracted current value. The beam current suitable for subsequent acceleration can be determined from the next plot, which presents dependencies of current of negative particles on the first collector which receives particles propagating within a cone having about 14^o value which is close to that obtained at remote distance. By extrapolation of ranges of slow decrease to the point with zero magnetic field strength, one can see that respective H^- current value should be about 50 mA.

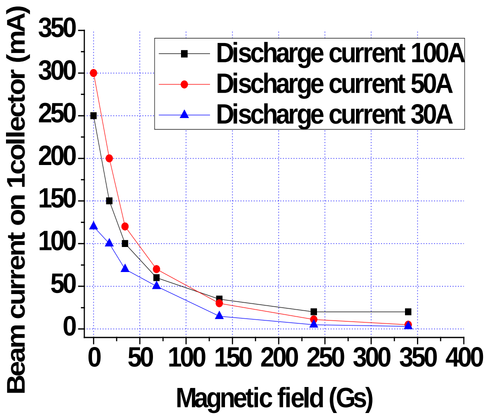

Fig. 7. Dependencies of current of negatively charged particles on 1 collector on magnetic field strength for three different values of discharge current in the source

Below in Fig. 8 values of current density on collectors at different magnetic field strength are presented. As in previous measurements, the beam energy was 10 keV. Discharge current in the source was 100 A. Each collector accepted the beam to a ring of 1 cm width. Since current receiving ring radius measured in centimeters coincides with the collector number, the plot also presents radial distribution of current at the collector plane.

One can see that maximum value of the beam current is observed in the center for both light and heavy negatively charged particles. Nevertheless, the beam periphery also possesses high enough density, which confirms strong angular divergence of the beam.

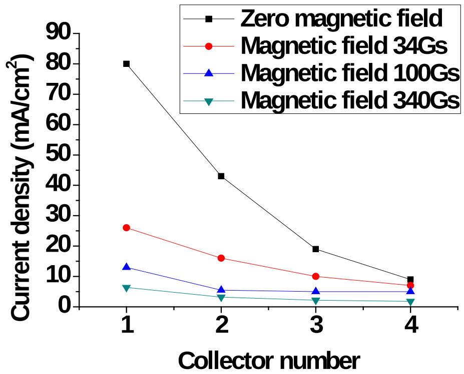

Fig. 8. Radial distributions of current density of negatively charged particles for different values of deflecting field

For increasing the source efficiency, further efforts on improvement of the beam extraction system are required.

CONCLUSIONS

We consider that essential increase of hydrogen negative beam current extracted from studied source with axial symmetry is due to plasma density growth at the expense of additional discharge in the source channel and decrease of H^- loss rate owing to their decay at collisions with electrons resulted from cooling of the electrons during their drift through near-anode region of magnetic field. Further modernization of the design, and increase of the source emission hole square enabled increase of H^- ion current from the source up to 20 mA under the same transport conditions, as in [2]. Radial dependencies of H^- current density obtained by means of sectioned collector at 8 cm distance from the source show that total H^- current exceeds 200 mA value near the source. H^- current density at the source aperture reaches the value of about 5 A/cm^2, which can give evidence to significant role of surface-plasma processes in H^- creation due to cesium presence in the source discharge. However, the beam possesses large value of the scattering cone of about 50^o. Although the current density maximum is observed at the axis, the current density decrease rate along the radius is slow enough. Thus, just less than a half of total H^-current comes to central collector (propagation cone angle of about 14^o). Strong beam divergence in the studied source is probably due to complexity of Pierce geometry obeying for extracting gap at large dimension of extracting slit in the source. The last circumstance implies use of the source in a tandem with additional focusing device. Activities aimed to this task are performed. As well, the measurements have shown that negative ion beam current value at its propagation for 50 cm (propagation cone angle of 12°) decreases from about 50 mA at the source aperture down to 20 mA at remote collector. The last fact can be explained by a process of electron loss by H^- ions at their collisions with particles of the gas flow, which is inherent to gas discharge sources of H^- negative ions. Accomplished researches have shown that pulsed discharge of combined type [2] with 100 V voltage and current values from several tens up to hundreds amperes is steadily ignited in the proposed source. At that, relation oscillations which can occur in some other types of H^- sources did not exist in our case.

Thus, one can state that highly efficient source of intense H^- ion beams of moderate energy is proposed. Improvement of extracting system at the source aperture is required.

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УСОВЕРШЕНСТВОВАНИЕ ИСТОЧНИКА ОТРИЦАТЕЛЬНЫХ ИОНОВ С КОМБИНИРОВАННЫМ РАЗРЯДОМ

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Представлены результаты исследований эмиссионных особенностей источника отрицательно заряженных частиц с комбинированным типом разряда. Получен циллиндрический пучок отрицательных ионов водорода с плотностью 5 А/см^2 на эмиссионной апертуре источника. Полный ток отрицательных ионов водорода достигает 200 мА, а электронов – 1,5 А, но имеет значительную расходимость на выходе источника. Источник имеет простую конструкцию и стабильные характеристики разряда с низким уровнем колебаний.

ВДОСКОНАЛЕННЯ ДЖЕРЕЛА НЕГАТИВНИХ ІОНІВ З КОМБІНОВАНИМ РОЗРЯДОМ

В.П. Горецький, А.М. Добровольський

Представлено результати досліджень емісійних особливостей імпульсного джерела негативно заряджених часток з комбінованим типом розряду. Отримано циліндричний пучок негативних іонів водню з густиною 5 А/см^2 на емісійній апертурі джерела. Загальний струм негативних іонів водню досягає 200 мА, а електронів – 1,5 А, але має значне розходження на виході з джерела. Джерело має просту конструкцію та стабільні характеристики розряду з низьким рівнем коливань.