PECULIARITIES OF HYDROGEN NEGATIVE ION BEAMS EXTRACTION FROM AXIALLY SYMMETRIC SOURCE WITH CROSSED FIELDS

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A comparison of emission features of axially symmetric H^- ion source with magnetron discharge and H^- source which incorporates additional hollow cathode discharge in series with main one is presented. It is shown that in the last case concentration of H^- ions in a region of emission hole of the source essentially increases. H^- ion current from the source with additional discharge increases by an order of magnitude. Additional plasma drift from assisting discharge and cooling of electrons at their passing through magnetic field region are considered as the reasons of determined growth of concentration of negative ions. H^- current density value of 150 mA/cm^2 on emission aperture of ion source is reached.

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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 values of 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 ion source with axial symmetry operating in pulse-periodical mode.

1. APROACH

The source with axial symmetry and cylindrical beam extraction along the axis was selected as a work model due to optimum correspondence to the requirements of focusing system operation. For such kind of the source, it is important to have the plasma low temperature and high enough density in the emission region. The last can be achieved by means of separation of the plasma generation zone from that of extraction of negative ions. Plasma cooling with simultaneous increase of its density can be realized at the expense of diffusion of converging plasma flow across magnetic field, or by obtaining hydrogen plasma in additional discharge and providing its flow and accumulation in the region of H^- ion formation and extraction. Version of combining two these options is interesting as well. For study of the influence of additional discharge on the efficiency of extraction of H^- ions from the source, two versions of its design were researched. The hollow cathode discharge was selected as additional one. It has been shown that the efficiency of extraction of hydrogen negative ions in the last case essentially increases, and the extracted electron current (I_e) to H^- current ratio $\Gamma=(I_e/I^-_H)$ is considerably improved. Hypotheses on the reasons of negative ion current growth in the source with additional discharge are proposed.

2. EXPERIMENTAL SETUP

We took into consideration an experience of construction of electron beam sources with gas discharge and axial symmetry [1-4] at designing of the negative ion source Particularly, discharge parameters of the source were chosen close to those described in [3], however, they were realized in axially symmetric geometry. As well as in [4], the discharge in crossed electric and magnetic field was selected as the main one. Experimental setup consisted from H^- ion source, pulsed valve for hydrogen supply, pulsed power supply modules for the valve and the source discharge.

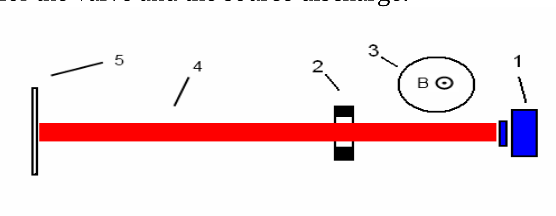


Fig. 1. Scheme of measurements of negative particle beam current from the source: 1 – negative ion source; 2 – magnetic shield; 3 – solenoid poles; 4 – beam of negatively charged particles; 5 – collector for the beam current measurements

For extraction and acceleration of the beam, high voltage was used which enable acceleration the extracted beam up to energy values of above 10 kV. Fig. 1 shows scheme of experiment on transport and measurement of negative particle beam parameters. The current value was measured by the current collector having 10 cm diameter at a distance of 50 cm from the emission plane. At that, both the overall current of negatively charged particles, and H⁻ ion beam current could be measured. Thus, the weak magnetic field was turned on in vicinity of extracting hole to remove the electron flow from beam.

The source exterior is shown in Fig. 2. The ion source has 17 cm diameter and 7 cm length. The source housing under the cathode potential is mounted inside isolator at the flange from external side of which electric power connectors and gas supply valve tube are seen. The front flange separated from the rear one by isolator and is under the ground potential.

Fig. 2. General view of negative ion source

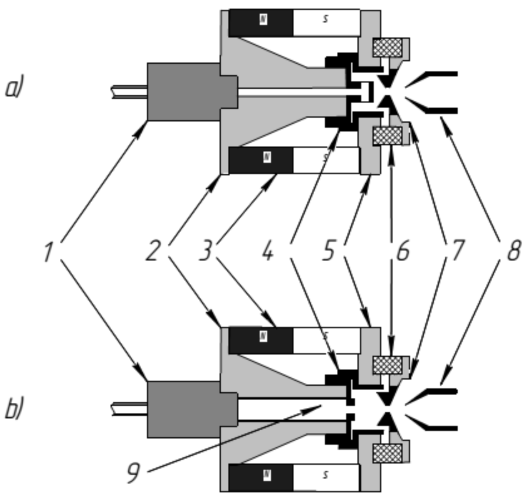


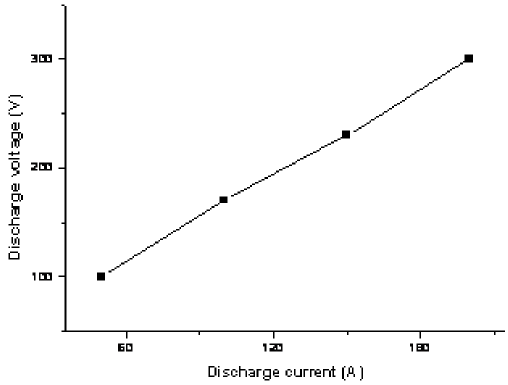
Fig. 3. Schemes of the two versions of H^- ion source: a – Source with magnetron discharge; b – source with additional hollow cathode discharge

At grounded flange elements of extracting systems are mounted. In operation regime the rear flange with the source is under negative potential of about 10 kV.

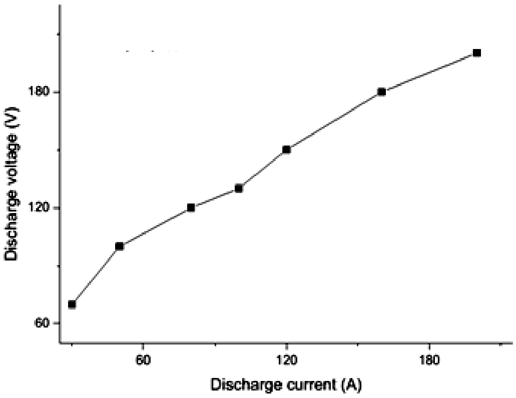
One can understand operation principle of the source from its schematic drawing in Fig. 3. The figure presents two versions of the source. Gas valve for hydrogen feed is marked as 1. The feed was done in pulsed way, in advance of 1.5 μs to turning on the source discharge pulse. The discharge was ignited between the electrodes 7 (anode) and 4 (cathode) in crossed electric and magnetic fields. The magnetic field of about 1 kGs strength was formed between the magnetic conductor poles 2 and 5 by means of ring magnet 3. The anode was separated from the cathode by ceramic isolator 6. Emission hole with 2 mm diameter are located in the anode insertion from molybdenum in washer 7. Elements marked from 1 to 7 were assembled at the rear flange. Extracting electrode 8 was assembled at the front flange. Accelerating potential was supplied to anode electrode 7 relatively to grounded electrode 8. All said above regards to both source versions a) and b). The difference of version b) was the presence of chamber 9. As it was shown by the experiments, at supply of the discharge voltage between electrodes 4 and 7, an additional discharge was ignited in the chamber which provided essential influence on emission features of the source. This discharge was glowing in a region where magnetic field was shielded. We name this discharge as the hollow cathode discharge.

3. RESULTS

Pulsed discharge was ignited by supply of the discharger voltage to electrodes 7 and 4 after hydrogen feed in presence of cesium vapor. Fig. 4 shows current-voltage characteristics of the discharge in the source with magnetron discharge, as well as in one with additional hollow cathode discharge.



a



b

Fig. 4. Characteristics of the discharge glow in the source with hydrogen: a − Source with magnetron discharge; b − Source with additional hollow cathode discharge

One can see that the discharge characteristics are close enough in both cases. At that, in the source with additional discharge the voltage is somewhat lower with the same current values. Measurements of negative particle current from the source was performed at the discharge current of 100 A. The discharge pulse had 500 μs duration. Repetition rate was ~ 2 Hz. It was determined that negative ion current from the source with hollow cathode comprised 5 mA, whereas the current in the first version of the source was an order of magnitude less. Fig. 5 presents the dependence of negative particle current from the source with hollow cathode measured at the collector on the strength of transverse magnetic field applied across the beam behind emission slit of the source. One can see that at the field increase up to 5 Gs negative particle current drastically decreases from 25 to 5 mA. We explain this behavior by the electron flow cutoff.

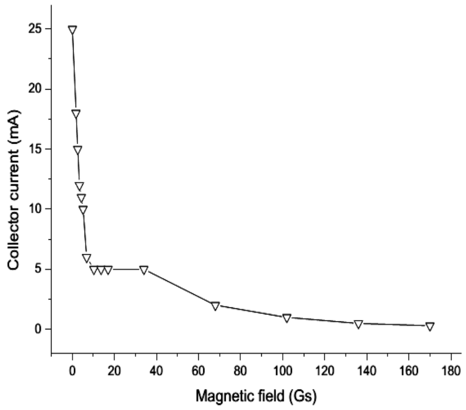


Fig. 5. Dependence of negative particle current onto the collector on deflecting magnetic field strength

In subsequent, the current remains unchanged up to the field strength of 40 Gs and exhibits noticeable decrease already at the field strength of about 200 Gs. This part shows behavior of H^- ion flow in the magnetic field. Results of negative particle current measurements are presented in Table.

The beam current on collector

	Magnetron source	Magnetron source with hollow cathode
(I_{H-})mA	0,5 mA	5 mA
(I_e)mA	5,5 mA	20 mA
I_e/I_{H-}	11	4

Note that in the case with assisting discharge the efficiency of negative ion extraction in the emission slit region considerably increases. As well, one can see that in this case negative ion portion in the negative plasma component is essentially higher.

4. DISCUSSION

By comparison of the measurement results for current values extracted from two versions of the sources of negative particles, one can see that presence of additional chamber with hollow cathode discharge results in an increase of concentrations of both negative ions and electrons and, consequently, overall plasma density in the region of emission hole. The most probable reason of that is the plasma drift from additional discharge region along magnetic field at the source axis. Increase of plasma concentration in the emission region results in the growth of formation rate of H^- negative ions in the processes of recharging of positive ions at the anode surface in vicinity of the emission region and negative ions formation in the plasma volume due to processes of dissociative attachment of electrons to vibrationally excited hydrogen molecules [3, 5, 6]. At the same time, one can expect cooling the plasma electrons at the drift from assisting discharge region through a zone of concentrated magnetic field. It in turn may essentially reduce the rate of negative ions destruction in a process of their collisions with electrons. We mentioned only the main processes responsible for negative ions existence in hydrogen plasma of the source. Other processes are possible as well. Particularly, efficient gas blocking is possible during the discharge glow in the source with combined discharge. It may essentially reduce NI beam destruction on the gas stream at the exit from the source. For now, one can resume that mentioned processes for considered type of the source require further detailed studies.

CONCLUSIONS

Accomplished experiments with axially symmetric H^- source with magnetron discharge have shown that introduction of additional discharge of hollow cathode type into the source enables essential increase of extracted current of hydrogen negative ions. H^- current density value about 150 mA/cm^2 on emission aperture is reached. It can be explained by the plasma density increase in emission region of the source. The last should lead to increase of the rate of formation of hydrogen negative ions in this region due to reactions of recharging of positive ions at the anode surface, and also due to volume processes of negative ions formation. One can also assume that the negative ions disappearance rate decreases due to lowering electron temperature in this region. The last is confirmed by an increase of contribution of negative ions current to overall current of the beam extracted from the source with additional hollow cathode discharge.

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ОСОБЕННОСТИ ИЗВЛЕЧЕНИЯ ПУЧКОВ ОТРИЦАТЕЛЬНЫХ ИОНОВ ВОДОРОДА ИЗ ОСЕСИММЕТРИЧНОГО ИСТОЧНИКА СО СКРЕЩЕННЫМИ ПОЛЯМИ

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Приводится сравнение эмиссионных свойств источника ионов H^- с осевой симметрией с магнетронным разрядом и источника H^-, в котором последовательно с основным дополнительно горит разряд типа «полый катод». Показано, что в последнем случае существенно возрастает концентрация ионов H^- в области эмиссионного отверстия источника. Ток ионов H^- из источника с дополнительным разрядом увеличивается на порядок величины. В качестве причин обнаруженного увеличения концентрации отрицательных ионов рассматриваются дополнительный дрейф плазмы из области вспомогательного разряда и охлаждение электронов при прохождении области с магнитным полем. Достигнутая величина плотности тока H^- в пересчете на эмиссионную апертуру источника составила не менее 150 мА/см^2, что в полтора раза превышает ранее полученные результаты.

ОСОБЛИВОСТІ ВИТЯГУВАННЯ ПУЧКІВ НЕГАТИВНИХ ІОНІВ ВОДНЮ З ВІСЕСИМЕТРИЧНОГО ДЖЕРЕЛА ЗІ СХРЕЩЕНИМИ ПОЛЯМИ

В.П. Горецький, А.М. Добровольський

Наведено порівняння емісійних властивостей джерела іонів H^- з симетрією навколо осі з магнетронним розрядом із джерелом H^-, в якому додатково до основного запалюється розряд типу «порожнистий катод». Показано, що в останньому випадку значно зростає концентрація іонів H^- в області емісійного отвору джерела. Струм іонів H^- із джерела з додатковим розрядом збільшується на порядок величини. В якості причин виявленого збільшення концентрації негативних іонів розглядається додатковий дрейф плазми з області допоміжного розряду та охолодження електронів при проходженні області з магнітним полем. Досягнута величина густини струму іонів H^- у перерахунку на емісійну апертуру джерела становить не менше ніж 150 мА/см^2, що в півтора рази перевершує попередні результати.