H^- Ion Source with Inverse Gas Magnetron Geometry for SNS Project

V.A. Baturin, P.A. Litvinov, S.A. Pustovoitov, A.Yu. Karpenko

Institute of Applied Physics, National Academy of Sciences of Ukraine, Sumy, Ukraine

Email contact of main author: baturin@ipflab.sumy.ua

Abstract. The work is dedicated to the experimental investigation of the intense volume-plasma H^- ion source. Formation of ions occurs in a volume of hydrogen plasma (without additives of cesium) due to two-step dissociative attachment of thermal electrons to vibrationally excited molecules H_2. Preliminary experimental researches of two parameters of the upgraded source - emission density of H^- ions and gas flow are represented below. In plasma volume of non-cesium H^- ion source the conditions for obtaining of increased density of H^- ions in the field of adjoining to the emission aperture were realized. It was made due to increase of flow of slow electrons to plasma adjoining to the emission aperture and their retention in this volume, and also due to decrease of gas pressure in an accelerating interval of a source.
The advancing of electrode system of the emission chamber of a source has allowed receiving the value of an emission density of H^- ions equal 550 mA/cm^2.
The designed source has high operating characteristics. It has rapid starting. The current of H^- ions with nominal parameters is usually reached in 1-2 minutes after achievement of necessary vacuum conditions and supply of high voltage. Earlier version of non-cesium source worked in the structure of RFQ accelerator for a long time.

1. Introduction

The plasma dual-chamber of H^- ion source having a rapid starting, reliable and long-time operation and also simplicity in service was designed at the Institute of Applied Physics NAS of Ukraine for the injector of a high energy accelerator. In more details design of this source can be found in reference [1]. It is a non-cesium ion source working on the basis of tubular discharge. For plasma generation the inverse gas magnetron in longitudinal magnetic field is used. The dual-chamber design of a source allows receiving rather easily necessary vacuum conditions, using pumps with average speeds of pumping. At high-power of discharge it is capable to supply an emission density of H^- ions current exceeding 220 mA/ cm^2.
The record values of emission density of H^- ions were obtained from the surface - plasma sources. However in some cases the using of these sources creates problems connected with existing of cesium vapors in their gas-discharge chambers. This fact, and a number of other circumstances, stimulates the development of non-cesium H^- ion sources. At the Institute of Applied Physics NAS of Ukraine the activities on advancing of earlier version of an axial - symmetrical source described in reference [1] are carried out.
Preliminary experimental researches of two parameters of the upgraded source - emission density of H^- ions and flow of working gas are adduced below. The increase of value of the first parameter and the decrease of value of the second one, are actual for using of ion sources in a structure of injectors of modern accelerators. These purposes in a described source are obtained by means of increase of a flow of slow electrons into the emission area and optimization of pulse supply of hydrogen into its discharge chamber.

2. Description of the setup

The scheme of the upgraded source is shown in Figure 1. The activity of this source is grounded on the most effective for today mechanism of formation of negative ions in a volume of hydrogen plasma (without cesium vapors). It is two-step process of dissociative attachment of low electrons by vibrationally excited molecules H_2 [2]. The cross-section of this process quickly grows up to a significant size (≥ 10^{-17}см^2) with growth of oscillatory quantum number at electron energy of several electronvolt. The main contribution to generation of H^- ions is introduced by molecules, exited on levels $\nu = 5 - 11$. The formation of vibrationally excited molecules realizes basically by fast electrons (> 10 eV). The optimization of conditions for vibratory excitation of molecules and for the subsequent formation of negative ions in this source is realized due to the creation of a gas discharge system generating in the emission chamber two areas of plasma - peripheral, with a rather large fraction of fast electrons and internal paraxial with slow electrons.

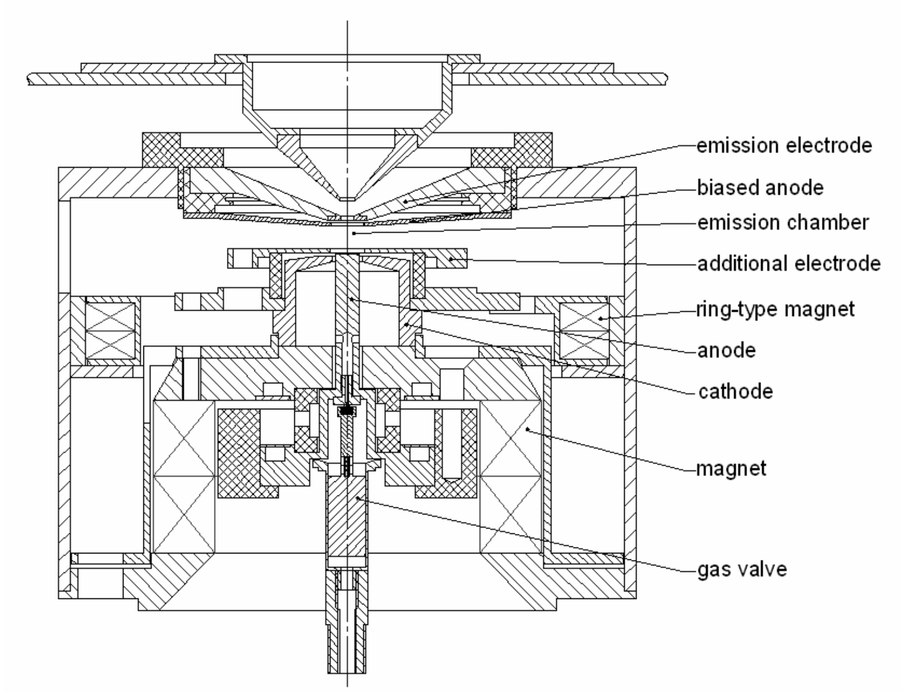

FIG. 1. Schematic of ion source with an inverse gas magnetron geometry.

The discharge chamber consisting of the cathode and anode represents inverse gas magnetron geometry, which works on the basic of glow discharge in crossed ExH fields. In the inverse magnetron of the given design it is possible to realize both magnetic and electrostatic retention of fast electrons. The superposition of a longitudinal magnetic field excited by magnets Sm-Co_5, increases a life time of fast electrons, which start from a cylindrical surface of the cathode to a central anode. The cathode walls of the gas magnetron provide the retention of electrons along a magnetic field. As a result a life time of fast electrons in the chamber of the magnetron increases. They experience numerous collisions with atoms of gas and have time to make sufficient number of ionizations before they get on a surface of an anode.

The ion source operates as follows. Under supply of a potential pulse on electrodes, the discharge is excited in the chamber. The generated plasma at sufficient width of an annular slot penetrates along a magnetic field into the emission chamber and extends up to an emission electrode. Additional electrode, which is under the positive potential relative to the anode of the magnetron, provides reliable plasma drawing from the magnetron into the emission chamber of the source.

Due to formation of double layer before a narrow annular slot at magnetron output, fast electrons are delivered to the area of its volume. In peripheral plasma conditions favorable for vibrational excitation of molecules are created. Internal paraxial plasma, formed by diffusion of peripheral tubular plasma across a magnetic field, will contain the vibrationally excited

molecules and the enriched fraction of slow electrons, while the fraction of fast electrons does not penetrate here because of the action of magnetic filter. Thus, in the internal plasma there are necessary conditions for effective realization of a finishing phase of two-step process of formation of negative ions.
It is necessary to mark, that in a considered source, the magnetic field of the filter by a natural mode coincides with a magnetic field of gas discharge and, accordingly, is formed by a general magnetic system. The magnetic system is designed on the basis of permanent Sm-Co_5 magnets which create in an interpolar gap magnetic field B_z = 0,09 – 0,12 T. For correction of a magnetic field in emission area of an ion source the ring-type magnet was used (Sm-Co_5) with a radial magnetization.
One of the important problems at optimization of H^- source activity is the optimization of gas flow. On the one hand for achievement of maximum density of negatively ions it is necessary to increase a gas pressure in the discharge chamber of a source, and on the other hand it is necessary to reduce a gas pressure in the field of formation of ion beam to reduce the destruction of H^- ions.

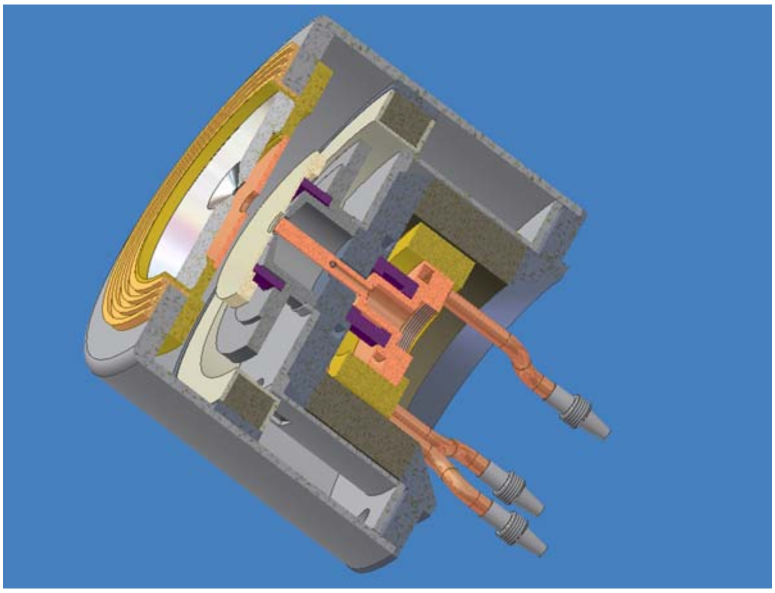

FIG.2. Design of the H^-source.

Design of the upgraded source is shown in Figure 2.
For reduce of gas flow in the upgraded source, we have applied a quick-operating valve designed by us [3]. In this valve, for maintenance of a short gas pulse with a high rate of pulse rise, a hammer device is applied. Besides in the upgraded source a locking device of the valve is made as a unified structural member together with an anode of the magnetron. It has allowed to avoid practically completely the integrating of a gas pulse, and to reduce gas flow during a pulse. The power supply of the valve allows executing the adjustable delay between supply of gas into the discharge cell and discharge initiation in the source.
The design of a source allows supplying the necessary gas pressure difference between discharge and emission chambers.
Extraction of ions from a source is made from paraxial zone of the emission chamber. Suppression of accompanying electrons occurs due to their moving along a magnetic field onto the emission electrode serving as the source anode. Negative ions are practically not affected by the influence of magnetic field and at observance of a condition $\lambda_i > d$, they participate in emission of ion beam. Here λ_i – mean free path of a negative ion, d – distance from a place of its formation to the emission aperture.

3. Experimental results

3.1. Emission Characteristics

The ion source was placed in the vacuum chamber. The vacuum chamber was pumped out up to pressure 10^{-4} Pa by a diffusion pump with pump speed 2500 l/s. Electrodes of the ion source were cooled by water. The discharge current was varied within the limits of 30 -140 A with pulse duration within the limits 0,1 - 1,2 ms, pulses repetition rate - 1-5 Hz. H^- ion beam and accompanying electrons were extracted from the emission aperture 3,4 mm in diameter ($S_{em} \approx 0{,}09$ cm^2). Extraction voltage is 18 – 22 kV. In these experiments the formation of an ion beam was not made. To clean the ion beam from accompanying electrons the permanent magnets creating a cross-sectional magnetic field with magnetic-field strength ~ 0,01 T were established on an extraction electrode.
In a basic design of the ion source the energy distribution of electrons in internal paraxial diffuse plasma was determined only by parameters of peripheral plasma. It was not possible to change their energy and density in the area of extraction.
In modified version of the ion source we tried to create the mechanism permitting to operate slow electrons density near the emission aperture. Such mechanism can be realized by creation of potential difference between an emission electrode and internal paraxial diffuse plasma of a source across magnetic field. To realize this mechanism the design of the gas-discharge chamber of the source was changed as follows (Figure 3):

1. Near the emission aperture within a few mm the radial component of magnetic field B_r was built. It was reached by introducing of non-magnetic (graphitic) insert into an emission electrode.
2. At a distance of 0,2 mm from the emission electrode A1 one more electrode (biased anode A2) was inserted so that it was in the area of a radial component of magnetic field. This electrode is an anode of the emission chamber of a source.

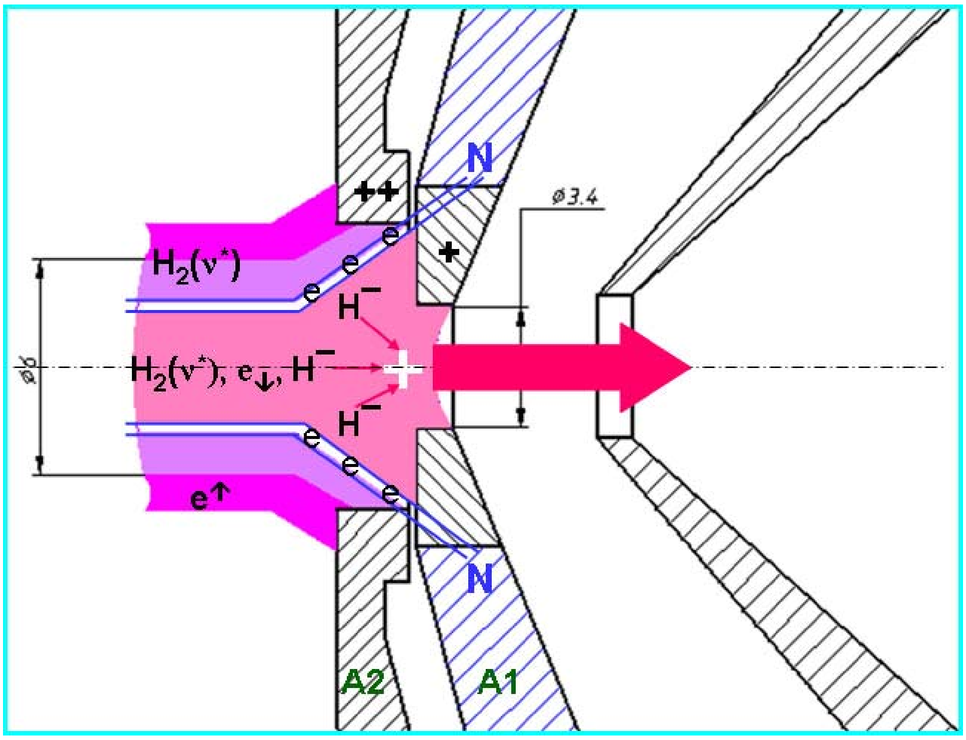

FIG.3. Schematic diagram of the modified emission chamber.

Applying to the emission electrode A1 controlled negative voltage offset concerning an biased anode A2 of the sources it will be possible to accelerate unmagnetized positive ions into the emission area. These ions, in turn, will capture slow electrons into the emission area. Besides the slow electrons in this area under operating of crossed ExH fields will commit a closed drift that will cause the increase of their life time in the emission area. If in same area of plasma there will be a sufficient quantity of an vibrationally excited molecules of hydrogen, it is possible to expect increase of density of H^- ions generating and accordingly their emission density.

Figure 4 shows the dependence of negative ion beam current and accompanying electrons as a function of discharge current at voltage between emission electrode and biased anode equal 10V. From the graph it is visible, that at a discharge current 130 A the emission density of H^- ions comes to ~ 480 mA/cm^2. The voltage extraction was 18 kV. Thus the modernization of a discharge chamber has allowed doubling the emission density of H^- ions current in comparison with basic design of a source.

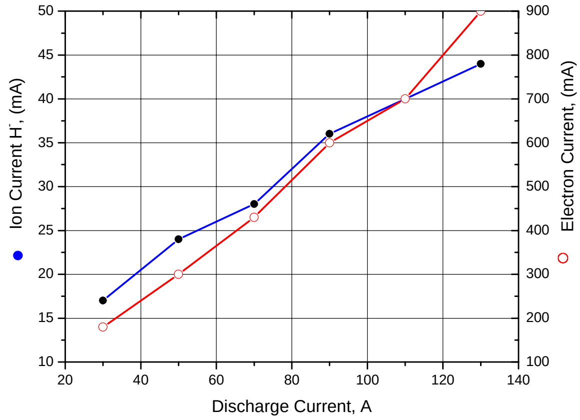

FIG. 4. Dependence of H^- ion current and accompanying electrons current on discharge current.

Dependence of I_e/I_i ratio as a function of discharge current is represented in Figure 5. The optimization of this ratio was not conducted.

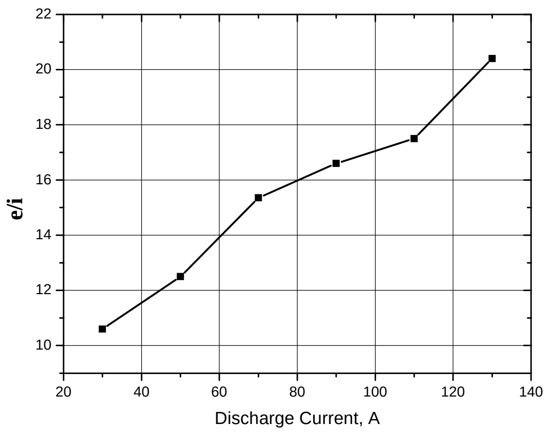

FIG. 5. Dependence of I_e/I_i ratio as a function of discharge current.

We suppose, that is possible to reach further increase of an emission density of H^- ions and decrease of value I_e/I_i by further optimization of topology of a magnetic field and geometry of anode of ion source in the emission area, extraction voltage and performance parameters of a source. Table 1 shows the achieved parameters of the source.

TABLE I: IMPROVED SOURCE PARAMETERS.

Discharge current	140 A
Ion beam current	~ 60 mA
Emission current density	~ 550 mA/cm^2
Ratio I_e/I_i	≤ 20
Pulse length	0,4 – 1,2 ms
Repetition rate	1 – 5 Hz
Extraction voltage	22 kV
Gas feed	0,025 cm^3/pulse

The oscillogram of discharge current, H^- ions current and accompanying electrons current at several values of a discharge current are represented in Figure 6. Pulse duration of discharge current - 0,7 ms. The voltage extraction was 22 kV.

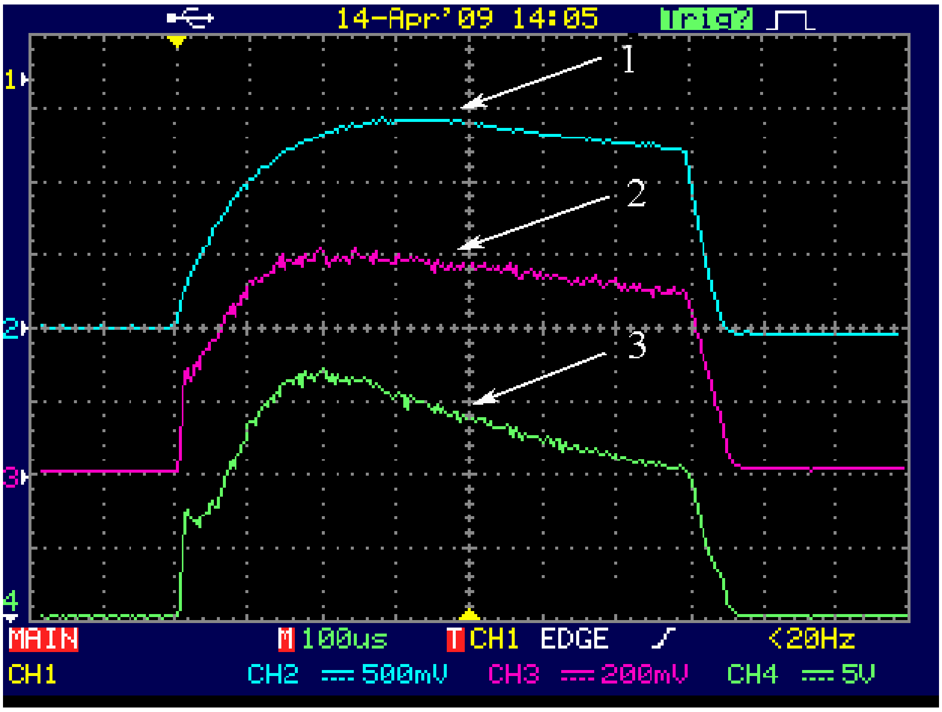

FIG. 6. Oscillogram of the discharge current (1), H^- ion current (2) and accompanying electrons current (3).

Measurements of ion beam emittance were conducted in earlier version of H^- source with slot-hole geometry. With the noiseless discharge for the current being 50 mA, the normalized emittance is 0,26π mm mrad across the emission slit and 0,64π mm mrad along it [4]. For this version of a source the emittance of a beam was not measured.

3.2. Gas flow

The gas flow was measured by a flow meter with differential pressure gage. At duration of a gas pulse 1,2 ms in the upgraded version of the ion source the hydrogen flow has compounded 0,025 cm^3/pulse. Usage of the new gas valve in a source has allowed reducing total gas flow. As a result the vacuum conditions in the field of primary acceleration of ion beam were improved, and consequently in this area the loss of H^- ions has decreased.

4. Conclusion

In plasma volume of non-cesium H^- ion source the conditions for obtaining of increased density of H^- ions in the field of adjoining to the emission aperture were realized. It was made due to increase of flow of slow electrons to plasma adjoining to the emission aperture and their retention in this volume, and also due to decrease of gas pressure in an accelerating interval of a source.

The value of density of H^- emission current ~ 550 mA/cm^2 is obtained.

The designed source has high operating characteristics. It has rapid starting. The current of H^- ions with nominal parameters is usually reached in 1-2 minutes after achievement of necessary vacuum conditions and supply of high voltage.

H^- ion source represented in the paper can be used as an alternative version of injector for the Spallation Neutron Source accelerator complex, presently under construction at Oak Ridge National Laboratory.

5. Acknowledgements

The authors would like to thank M. P. Stockli for the support. This work was supported partly by ORNL Subcontract No. 4000044353.

6. References

[1] KURSANOV, Yu., et al., "H- Source with the Volume-Plasma Formation of Ions" AIP Conference Proceedings 763, American Institute of Physics, Melville, NY, 2005, 229-234.

[2] BACAL, M., et al., "H^- and D^- Production in Plasmas", Phys.Rev. Letters ,42, 1538 (1979).

[3] BATURIN, V., et al., "A Quick-Acting Pulsed Gas Valve for a Cluster-Beam Source" Instruments and Experimental Techniques, 47, 417-422, (2004).

[4] LITVINOV, P., at el., " A volume negative-ion source for ion-beam machines" Nuclear Instruments and Methods in Phys. Research B, 171, 573-576 (2000).