A Broad Beam Ion Source with a Grid-Bounded Plasma Cathode[1]

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Abstract – A two-stage source of broad gas-ion beams have been developed and studied. A grid-bounded plasma cathode based on hollow-cathode glow discharge is used in the first stage and a magnetic system for creation of a peripheral magnetic field is used in the anode stage. The emission current of the plasma cathode having the emitting surface of ~ 3 cm^2 was adjustable from 0.1 to 1 A, the voltage across the bipolar diode between the source stages was 50 to 200 V, and the argon pressure of the second stage was preset between $0.6 \cdot 10^{-3}$ and $5 \cdot 10^{-2}$ Pa. The argon ion beam having an energy of up to 5 keV and a current of up to 130 mA was formed in a two-electrode ion optical system having a surface area of ~ 50 cm^2 with apertures 3 mm in size. The beam current increased with the second-stage voltage up to values accounting for ~ 20% of the plasma cathode emission current.

1. Introduction

A double-layer of space charge is formed between the cathode and anode plasmas of two-stage ion source with separated cathodic and anodic regions of the gas discharge. Electrons acquire additional energy (a few tens of eV) in the double layer, providing efficient ionization of the gas in the anode stage. Either hot [1] or cold [2] cathodes or a high-frequency discharge [3] is used currently as such sources in the cathode stage. The functional division of individual stages of the ion source allows optimization of processes in each of the stages [4]. The use of a multicusp magnetic field in the anode stage ensures both high homogeneity of the plasma and highly efficient extraction of ions from the plasma. A fine grid installed between the stages [5] provides independent adjustment of the current and the energy of fast electrons. This feature adds to the control of the plasma density, its mass composition and the charge state of ions. Additional acceleration of electrons in the layer and provision of conditions for their efficient energy relaxation improve energy performance of the cold-cathode ion source since the proportion of energy consumed for the cold cathode emission is reduced. The present study deals with characteristics of the source over wide intervals of the glow discharge current, the second-stage voltage, and the gas pressure.

2. Ion Source Design

The cathode and anode stages of the source were made as hollow cylinders 150 mm across, which ended with conical branch pipes on the side of the grid 2 (Fig. 1).

The electrode material was stainless steel. The rod trigger electrode 4 was aligned with the axis of the hollow cathode 1. The side surface of the cathode mounted permanent magnets, which formed a multicusp magnetic field reducing the discharge operation voltage and minimal working gas pressure. The cathode with the dissipated power of up to 0.5 kW was force-cooled with water circulated through the ducts 9. The surface of the second-stage anode 3 mounted twelve linear rows of permanent magnets 5 made of a samarium-cobalt alloy. The magnets were 10×10×20 mm in size. The magnetic field induction at the poles was 0.4 T. The stainless-steel grid with meshes 0.6×0.6 mm in size, which had geometrical transparency of 66%, was fixed in a holder fitted between two fluoroplastic insulators.

The two-electrode ion optical system comprising screen 6 and accelerating 7 electrodes was mounted on flanges, which were separated by a high-voltage insulator 10 made of plexiglass. The working surface area of the beam forming system was 50 cm^2. The ion optical system had apertures 3 mm in size. Ion-optics electrodes were made of a molybdenum sheet 0.5 mm thick. The ion beam current was measured in the circuit of the grounded collector 8.

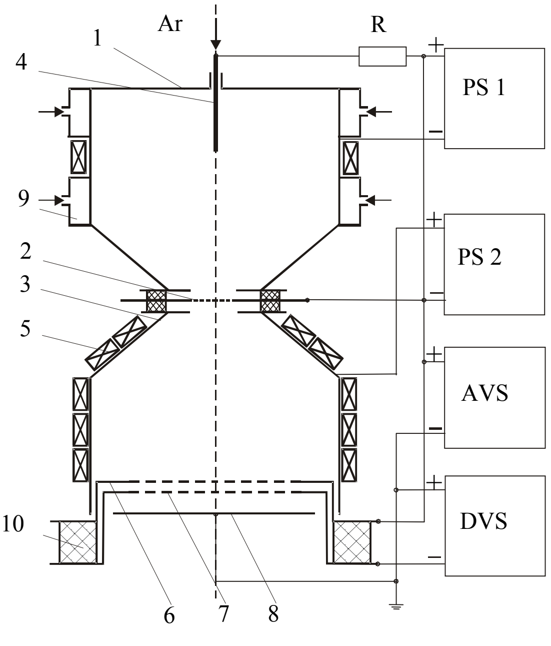

Fig. 1. Schematic picture of the ion source

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The discharge stages were powered from supply units providing intermediate frequency transformation: the discharge current stabilizer PS1 adjustable between 0.1 and 1 A and the voltage voltage stabilizer PS2 with step controlled output voltage of 0 to 200 V. The accelerating voltage source AVS provided an output voltage of up to 6 kV at a current of up to 0.2 A. The DVS source with an output voltage of up to 2 kV cut off secondary electrons.

The ion source was installed on the vacuum chamber, which was evacuated using an AVDM-400 vacuum plant with an oil-vapor pump. Forevacuum was produced by an AVZ-20 pump. A gas (argon) was leaked into the cathode cavity of the ion source. The gas flow rate did not exceed 10 cm^3/min. The pressure values, which will be cited below, were measured in the vacuum chamber.

3. Results of the Ion Source Testing

Figure 2 presents current-voltage curves of the discharge between the hollow cathode and the grid.

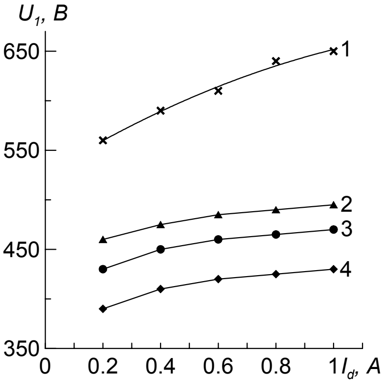

Fig. 2. Voltage-current characteristics of glow discharge between hollow cathode and grid. Gas pressure in vacuum chamber: $0.7 \cdot 10^{-2}$ (1), $1.3 \cdot 10^{-2}$ (2), $2.7 \cdot 10^{-2}$ (3), $5.3 \cdot 10^{-2}$ Pa (4)

When the second stage was turned on, the discharge operation voltage dropped by ~ 20 V due to the reverse ion flow to the cathode chamber. The ion beam current increased with growing energy of fast electrons (Fig. 3), which was determined by the potential difference U_2 between the second-stage electrodes. The rise of the bean current with growing discharge current was limited by the carrying capacity of the ion optics used. The interval of working pressures, over which the beam current increased with pressure, was also bounded above. The maximum current of 5-keV ion beams was ~ 130 mA.

Emission characteristics of the ion source, which were measured at an accelerating voltage of 5 kV and different voltages across the second stage, exhibited an almost linear behavior (Fig. 4). Current-voltage dependences of the ion source were linear over wide intervals of beam currents and accelerating voltages, except limiting regimes with the beam current exceeding 100 mA, in which the ion optics was serviceable only at voltages of 4–5 kV or larger (Fig. 5).

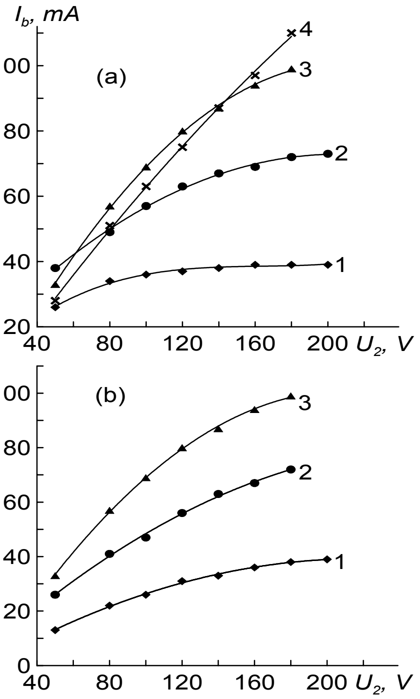

Fig. 3. Ion beam current as a function of grid-to-anode voltage on condition that discharge current is constant $I_d = 0.6$ A (a), gas pressure is constant $p = 0.7 \cdot 10^{-2}$ Pa (b). (a): $p = 0.7 \cdot 10^{-2}$ (1), $1.3 \cdot 10^{-2}$ (2), $2.7 \cdot 10^{-2}$ (3), $4 \cdot 10^{-2}$ Pa (4); (b): $I_d = 0.2$ (1), 0.4 (2), 0.6 A (3)

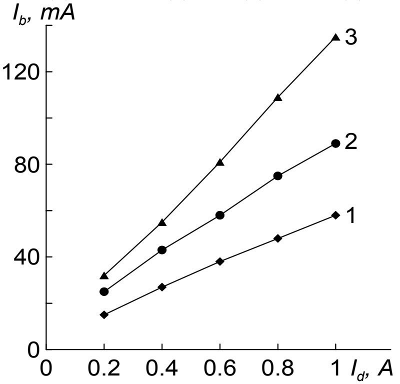

Fig. 4. Emission characteristics of the ion source. Gas pressure $2.1 \cdot 10^{-2}$ Pa. Grid-to-anode voltage $U_2 = 50$ (1), 100 (2), 150 V (3)

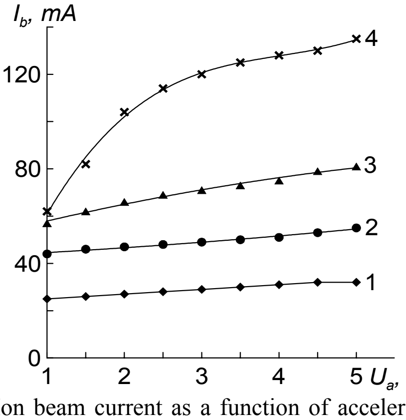

Fig. 5. Ion beam current as a function of accelerating voltage. Gas pressure $2.1 \cdot 10^{-2}$ Pa. Discharge current $I_d = 0.2$ (1), 0.4 (2), 0.6 (3), 1 A (4)

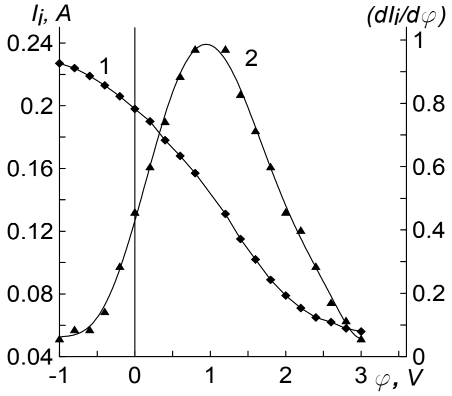

Fig. 6. Ion current as a function of retarding voltage (1) and energy spectrum of ions extracted from plasma (2). Gas pressure $2.7 \cdot 10^{-2}$ Pa. Discharge current 0.4 A. $U_2 = 200$ V

The maximum energy efficiency of ion generation in discharge could be estimated from the ratio between the ion current to the screen electrode without the ion extraction and the product of the discharge current by the sum of voltages across the first and second stages, $\eta_1 = I_s/I_d(U_1 + U_2)$, on condition that efficiency of electron extraction from the plasma cathode approached 1. At a maximum ratio $I_s/I_d \sim 1.5$ and $(U_1 + U_2) \sim 600$ V, η_1 was equal to ~ 2.5 A/kW. The ratio between the beam current and the ion current to the screen electrode at a voltage $U_2 = 600$ V was 0.15–0.25. Therefore, the energy efficiency of the ion source in this regime could be $\eta_2 \sim 0.375$–0.625 A/kW. Only the lower limit of the calculated interval of η_2 values was reached in the experiments, because the growth of the ion current to the screen electrode was not followed by the corresponding increase in the beam current as the pressure was brought to over $2 \cdot 10^{-2}$ Pa.

Non-uniformity of the ion current density distribution over the beam cross-section, which was measured earlier [6] on a prototype ion source, did not exceed 10%. High stability of emitting plasma parameters was confirmed by measurements of the energy spectrum of ions extracted from the anode plasma (Fig. 6). The half-width of the ion energy distribution was several eV.

4. Conclusion

A cold-cathode ion source generating broad ion beams with a uniform distribution of high ion beam current density over the 50 cm^2 cross-section area has been designed and fabricated. The beam current of argon ions was up to 120 mA at an accelerating voltage of up to 5 kV. The ion source is capable to operate at gas pressures as low as $0.6 \cdot 10^{-3}$ Pa. High energy efficiency of the ion source (~ 0.3 A/kW) is due to a large proportion of electron energy consumed for ionization, effective confinement of fast electrons, and extraction of considerable part of ions from the plasma generated in a magnetic bucket. A prolonged lifetime of the grid unit is due to the increase in the total surface area of the grid and the use of a grid with large meshes and thicker grid wires.

The source may be used in applications combining requirements of a long lifetime of the cold cathode and a low content of metal ions in the ion beam.

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