EXPERIMENTAL INVESTIGATION RESULTS ON THE VERSATILE INJECTOR OF ION, ELECTRON, AND ION-ELECTRON BEAMS

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Abstract

Successive or simultaneous treatments of a surface with various ion and electron beams considerably increase its ion implantation capabilities. A plasma-beam type of injector for producing charged-particle beams of cylindrical and ribbon shape is described. Ribbon beams of hydrogen ions (with a width of 120 mm and a current of 0.6 A) and axially symmetric mixed electron-ion beams with a diameter of 3 mm were obtained with this injector. The total hydrogen-ion current in an electron-ion beam was 50 mA (proton content was 80%). Ribbon beams of negative ions of hydrogen (with a width of 40 mm and a current of 2 mA), as well as beams of multiply charged nitrogen, argon, and aluminium ions, were obtained.

1 INTRODUCTION

Successive or simultaneous treatments of a surface with various ion and electron beams considerably increase its ion implantation capabilities. The use of space charge (or current)-compensated mixed electron-ion beams for this purpose allows the generation of high-density ion currents, as well as ultra-thin beams, on the irradiated surface; the treatment of dielectric surfaces without electric breakdowns; annealing of arising defects simultaneously with the implantation; and the optimization of radiation heating under vacuum [1,2].

In this article, we describe an injector [3] for the production of electron, ion, and mixed electron-ion beams. Its specific feature is the use of part of the energy stored in the electron beam to obtain working substance ions in the plasma-beam discharge (PBD), changing the power fraction consumed by this function from zero to maximum value comparable with the injected electron beam power.

The ions of both gaseous and solid substances can be obtained in this way. In the latter case, the substance is evaporated by an electron beam. The presence of a high-energy electron beam in the ion formation domain allows the injector to be used for the production of multiply charged ions.

2 GENERAL LAYOUT OF INJECTOR

The electron-ion injector consists of a modified Peirce gun with a partially screened LaB_6 cathode and a gas-discharge tube. The electron beam is focused by an axially symmetric magnetic field of solenoids. A working substance (gas) is fed into the gas-discharge tube. The electron beam generates a plasma-beam discharge due to the interaction with the working substance.

The ions produced in the discharge tube can be withdrawn both along and across the magnetic field. In the former case, a mixed electron-ion beam is produced, in which the ions are focused by the space charge of the electron beam. In the latter case, ribbon ion beams can be shaped. A photograph of the electron-ion source is presented in Fig. 1. The main parameters of the source are given in Table 1.

Table 1: Injector specifications

Parameter	Value
Electron energy (variable)	up to 50 keV
Electron current	up to 10 A
Ion energy (variable)	up to 50 keV
H+ currents: a) axial beam b) ribbon beam	 50 mA 600 mA
Width of ribbon beam	120 mm
Pulse duration	100 μs
Pulse repetition rate	1 Hz

3 EXPERIMENTAL INVESTIGATIONS

3.1 Hydrogen Ion Ribbon Beam

Results of the measurements of the hydrogen ion ribbon beam intensity distribution are shown in Fig. 2. All the characteristics were obtained for the same primary electron beam currents and energies (4 A, 35 keV). The extracting voltage was 20 kV. The gas was fed into the discharge tube through the hole in the middle of the tube, opposite to the emission slot.

Curve *1* in Fig. 2 was obtained for the hydrogen pressure in the discharge tube p ~10^{-3} Torr, and with the edge diaphragms were under a negative potential of 600 V

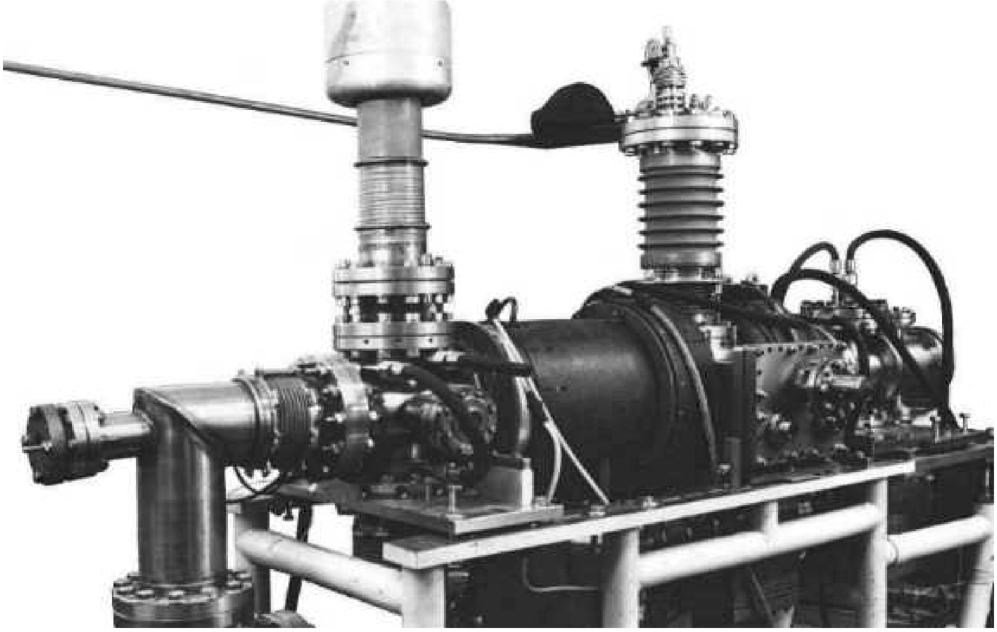

Figure 1: A photograph of the electron-ion source.

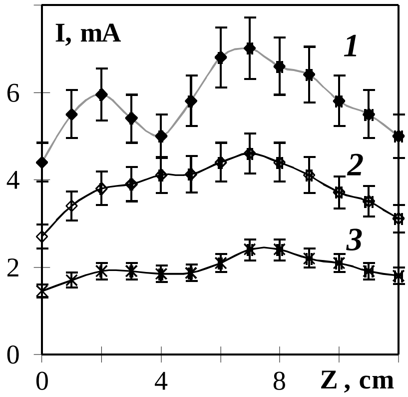

Figure 2: Hydrogen ion ribbon beam intensity distribution over the ribbon width: (*1*) I = 0.6 A, p = 10^{-3} Torr, and PBD + electron reflector; (*2*) I = 0.4 A, p = 5×10^{-3} Torr, and PBD; (*3*) I = 0.2 A, p = 10^{-4} Torr, and PBD. The primary electron beam energy and current are 35 keV and 4 A, respectively.

relative to the tube side wall. The total ion beam current was I = 600 mA. Curves *2* and *3* in Fig. 3 were obtained for the equipotential tube, i.e., under the conditions of a classical PBD. It can be seen that pressure reduction in the discharge tube causes a decrease in the ion ribbon beam current. Simultaneous measurements of the ion component of the axial electron-ion beam showed that it depends to a smaller degree, on the pressure (50, 45, and 43 mA, respectively).

3.2 Multiply Charged Ion Beams

Beams of multiply charged ions were also obtained with the source. The ion charge spectrum was measured for the ribbon beams in the focusing solenoid magnetic fields. In Table 2, we present the charge compositions for the nitrogen, argon, and aluminium ion beams. The extracting voltage was 20 kV. It is worth noting that the beam charge spectrum shifts to greater charges with the increase in the electron beam power.

To obtain Al vapors and to ignite the PBD in it, we heated and evaporated Al by the primary electron beam [4]. To do this, an Al plate 170 mm in length was placed in front of the emission slot in the discharge tube. The distance from the tube axis to the plate surface edge nearest to the electron gun was 2 mm; at the opposite edge, it was 0.5 mm. A part of the electron beam came against the entire plate length and heated the plate. The PBD in the Al vapors was already initiated at the first electron beam pulse with a delay of 60-70 μs with respect to the pulse front. For subsequent pulses, the delay fell to 5-10 μs and then remained constant. This indicates that a thermal equilibrium has been achieved on the aluminium surface, whereas the beginning of intense evaporation, which is sufficient to ignite the PBD, approximately coincides in time with the electron pulse duration. The evaporated substance is spent in smaller amounts. In the experiments that were carried out, the aluminium evaporation consumed up to 50% of the electron beam current.

Table 2: The charge compositions for ion beams

Element	**Electron current, A**	**Electron energy, kV**	**Ion charge**		
			+1	**+2**	**+3**
			Ion current, rel. units		
N	2	35	1	1.2	0.6
Ar	3	35	1	1.4	0.7
Al	5	40	1	1.2	0.65

3.3 H^- Ribbon Beam

The ribbon beam of negative hydrogen ions H^- was obtained in the cylindrical discharge tube with an inner diameter and length of 8 and 160 mm, respectively; in its middle, the tube had an expanded section with a diameter and length of 40 and 60 mm, respectively. A longitudinal emission slot 1×40 mm in size was cut in the middle part of the tube. Under hydrogen pressure in the discharge tube $p \sim 5\times10^{-3}$ Torr, we obtained a H^- ion beam with a current of 2 mA and an energy of 15 keV. The current of accompanying electrons was 10 mA.

We observed a dependence of the negative hydrogen ion current on the primary electron beam current. For a primary electron energy of 10 keV, the H^- ion beam existed only when the electron beam current was varied in a narrow range beginning from 0.3 A (the PBD ignition threshold). A maximum of the H^- beam intensity was observed for an electron current of 0.7-0.8 A, whereas no H^- ions were detected for a current of 1.5 A and higher.

3.4 Irradiation of Magnetic Film

To test implantation capabilities of simultaneous and successive treatments of a surface with ion and electron beams, the investigations of the magnetic film features were done by means of Mössbauer spectrometry. A film of cobalt ferrite ($CoFe_2O_4$) with a thickness of 5 μm was processed by irradiation with the following parameters: 1) electrons with a dose of $D_e=10^{15}$ cm^{-2} and energy E_e = 40 keV, 2) protons with $D_{p1}=10^{15}$cm^{-2} and $D_{p2}=10^{16}$cm^{-2} with E_p=80 keV, 3) simultaneously electrons and protons with above-stated energy and $D_e=D_p=10^{15}$cm^{-2}.

Table 3: Various kind irradiation influence normalised degree on $CoFe_2O_4$

Radiation type	**Particle flux, cm^{-2}**	**Energy, keV**	**Influence degree**
Protons	10^{16}	80	1
Protons	10^{15}	80	0.65
Electrons	10^{15}	40	0.33
Protons & Electrons	10^{15} 10^{15}	80 40	0.86

In Table 3 the influence comparison results of irradiation flow various kinds on ferrite film are given. The irradiation result comparison was carried out on intensity ratio of the spectrum appropriate lines. Conditionally given parameter is accepted equal 1 with irradiation by protons with $D_{p2}=10^{16}$cm^{-2}.

From Table 3 it is visible, that the simultaneous irradiation by electron and ion beams with a flow $D_{e,p}=10^{15}$cm^{-2} provides a degree of influence on the initial material comparable to an material irradiation by protons with a flow $D_{p2}=10^{16}$cm^{-2}, that testifies the technique developed efficiency and proves perspective of the designed equipment.

4 FEATURES OF PDB-BASED INJECTOR

The use of PBD for producing and heating plasma allowed us to develop a versatile injector of ion, electron, and electron-ion beams. The electron gun generating a high-power electron beam, which initiates and sustains the PBD in the discharge tube, is taken out of the domain of intense ionization and runs under high vacuum. This provides for the following advantages:

(i) reducing the ion flow to the gun cathode so that the cathode service life and its continuous operation time are increased;

(ii) increasing and easily varying the ion beam power and, hence, the power fed to the plasma, thus choosing optimal conditions for the multiply charged ion and ribbon beam generation;

(iii) using the electron beam to evaporate solid working substances in the discharge tube; and

(iiii) using the electron beam for shaping and further focusing the axial ion beam.

5 CONCLUSIONS

Test results of the injector operation confirm the possibility of its use as a versatile implantation device for irradiation of large material surfaces with ribbon beams and for irradiation of materials with ion and electron beams possessing a density current high. The tests showed that the ion beam intensity and charge composition depend on the electron beam power. Variation of the beam power by changing its intensity affects the multiply charged ion beam intensity to a greater extent than the beam charge composition. Oppositely, variation of the electron beam power by changing the electron energy produces an effect on the beam charge composition. This indicates that the primary beam electrons play an important role in the multiply charged ion formation.

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