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GENERATION OF COMPENSATED ION BEAMS FROM SOURCE WITH OSCILLATING ELECTRONS

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The generation of compensated ion beams from electrically unsymmetrical reflecting discharge was investigated. The spatial location of a compensation zone, the optimal values of operating gas pressures Ð = (0,8 ÷ 1)·10^{-4} Torr and potential difference between cathodes ΔU = 80Â were determined. The way to control the current compensation degree of the extracted ion beam from a several to 100% was found.

Introduction

The ion beam compensation problem arises during the ion beam treatment of dielectrical or solitary conductive surfaces under the condition of high vacuum. The necessity of neutralization both the ion space charge and total current of an ion beam is responsible for two undesirable effects. One of them is the influence of the local electrical fields created by the uncompensated space charge of an ion beam. The other is the high stationary potential of a treated surface, which is set with equality of the total currents of charged particles incoming to the surface and leaving one. If the ion beam compensation is not realized these effects result in limitation of an extractable ion current, sufficient deceleration of ions and cessation of their inflow on a treated surface.

At the pressure when the gas neutralizaton is not effective [1] the ion beam compensation is realised by injection of opposite sign charged particles in the beam. Usually, the electrons produced by heated emitters placed on the ion beam path are used as a compensating component [2]. However, the using of heated emitters sets the limitation on the lifetime of such devices and does not permit to apply them during the operation with chemically active working substances. Therefore, the ion sources, which have not the heated emitters, are very promising for generation of compensated ion beams.

In present paper the results of experimental investigation of compensated ion beam generation from plasma of the electrically unsymmetrical reflective discharge are presented. The experiments were performed in the high-voltage regime of discharge burning [3]. In this regime the excitation of intensive high-frequency oscillations in the anode layer are accompanied by generation of the electrons with anomalously high energy [4-5]. In this cause under certain external parameters of discharge burning the current compensation of the extracted ion beam was observed [6]. However, the main disadvantages of compensated beams obtained in such way were the low intensity of extracted ion current and high spatial inhomogeneity of compensation degree in the beam. The use of an electrically unsymmetrical reflective discharge permits sufficiently to increase the intensity of extracted beams of charged particles [7]. The perspectives of application of the ion sources based on such discharge for the surface treatment are connected with resolving of the ion beam compensation problem.

Techniques and experimental results

The experiments were performed on a penning discharge set-up as schematically shown in Fig. 1. The electrode system consisted of a cylindrical anode 4 and cathode 5 with 8 cm and 4 cm in length, respectively, as well as a flat cathode 3 were placed in vacuum chamber 1. The each of electrodes was 8 cm in diameter. The interelectrode clearances between anode and cathodes were 4 cm. The flat cathode 3 was made of a duralumin, but the cylindrical electrodes were stainless steel. The highvoltage power pack 8 supplied the discharge current up to 300 mA at the anode voltage up to 10 kV. The magnetic system 2 created the uniform magnetic field with intensity up to 1 kOe. The inhomogeneity of the magnetic field along system axis did not exceed 2%.

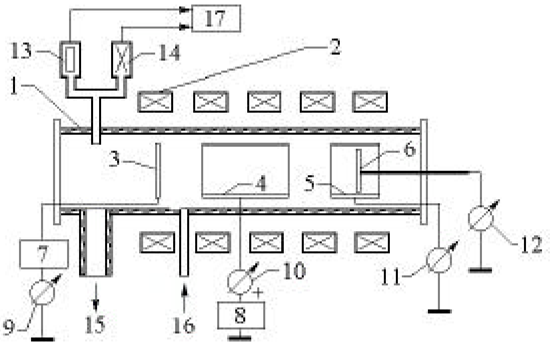

Fig. 1 Experimental installation diagram.
1 - vacuum chamber; 2 - magnetic system; 3, 5 - cathode; 4 - anode; 6 - collector; 7 - power pack; 8 - highvoltage power pack; 9, 10, 11, 12 - milliampermeters; 13 - thermocouple manometric converter; 14 - ionization manometric converter; 15 - evacuation; 16 - leak-in.

In run of experiments the cylindrical cathode 5 was grounded, but the potential of the flat cathode 3 was varied in range of U_{c1} = (-400 ÷ +400) V. The electrical unsymmetry in the system was created by the potential difference between cathodes $DU = U_{c1} - U_{c2}$, where U_{c1} is the potential of cathode 3, U_{c2} is the potential of cathode 5. The base pressure of vacuum chamber was about 5·10^{-6} Torr.

The investigations were carried out in the stationary discharge burning regime at the pressure of working gas (nitrogen, oxygen, argon) $Ð = (0,1 \div 1)\cdot 10^{-4}$ Torr, at the intensity of external magnetic field $Í = (0,1 \div 1)$ kOe, anode voltage $U_{à} = (0,5 \div 3,5)$ kV and discharge currents $I = (0,1 \div 100)$ mA. The plasma density $n_e \sim (1 \div 10)\cdot 10^{9}$ cm^{-3} and the electron temperature $Ò_{å} \sim (20 \div 60)$ eV were determined by probe techniques. The total current of the charged particles extracted from side of cylindrical cathode 5 was measured by movable flat copper collector 6. The charged particles beams were extracted from discharge along system axis. The radial distribution of the current density and energy of charged particles were investigated by Faraday cylinder and multigrid electrostatic analizer.

In order to determine the range of operating gas pressures which are most optimal for generation of compensated beams, it was studied the dependence of current densities of extracted charged particles on working gas pressure at *DU* = 0 V, *Í* = 600 Oe and U_a = 1,5 kV (Fig. 2). As can be seen from Fig. 2, the generation of compensated ion beams was observed at the working gas pressure $Ð < 10^{-4}$ Torr. When $Ð > 10^{-4}$ Torr the discharge was passed into the low voltage regime of discharge burning. In this cause the anode voltage was reduced up to $U_a = (0,7 \div 0,8)$ kV, but the discharge current was increased sufficiently.

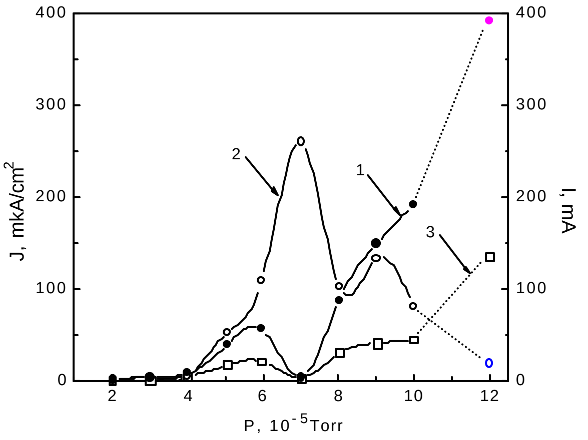

Fig. 2. Dependencies of ion current density (1), electron current density (2) and discharge cyrrent (3) on the working gas pressure.
U_a = 1,5 kV, *Í* = 600 Oe, *DU* = 0 V.

At the working gas pressures in range of $2\cdot 10^{-5}$ Torr to $7\cdot 10^{-5}$ Torr, the large radial inhomogeneity of current densities of charged particle beams was observed. Whereas, at $Ð = (8 \div 10)\cdot 10^{-5}$ Torr this inhomogeneity was decreased significantly, as seen from Fig. 3.

Also, the dependencies of current densities and energy spectrums of extracted charged particles on the potential difference between cathodes *DU* were investigated. The flows of charged particle to the discharge electrodes were studied simultaneously. The dependencies obtained are shown in Fig. 4 - 6. As can be seen from Fig. 4, the values of ion beam density and currents on discharge electrodes peeks at *DU* = 80V.

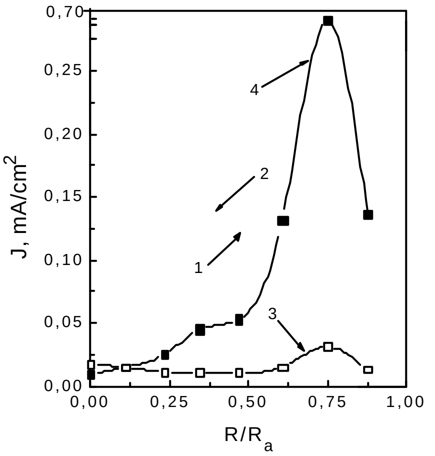

Fig. 3. Radial distribution of ion (1,3) and electron (3,4) current densities at the distance 1 cm from internal edge of cylindrical cathode 5. (R_a is anode radius).
U_a = 1,5 kV, *Í* = 600 Oe.
1, 2 - $Ð = 9\cdot 10^{-5}$ Torr, *DU* = 80 V.
3, 4 - $Ð = 4\cdot 10^{-5}$ Torr, *DU* = 0 V;

In this cause, the current compensation region of an ion beam was located at the distance 1 cm from internal end of the cylindrical cathode 5. With increasing of *DU* from 80 V to 300 V the current compensation degree of an ion beam was decreased up to a several percents at the same region, but the compensation zone was removed from cathode. At *DU* < 0 V, the electron current density exceeded the ion current density sufficiently. The energy spectrums of extracted ions were obtained with *DU* = 80V which is a most optimal for compensated beam generation. In the ion energy distribution the two peaks with the most probable energies of 0,4 kV and 1 kV were observed, as shown in Fig. 5. These energies corresponded to the values of plasma potentials in the central discharge region on axis and anode layer, respectively. In the energy distribution of beam electrons the two electron group were observed at *DU* < 0Â, as shown in Fig. 6 (curve 2). The most probable energy of the high-energy electron component corresponded to the value of a potential difference between cathodes *DU*. At *DU* > 0 V only one group of electrons with the most probable energy of about a several electronvolts was observed (curve 1).

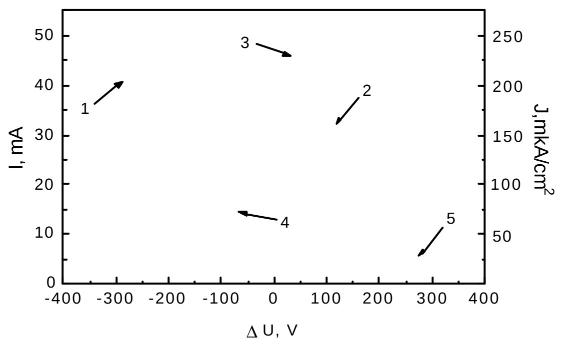

Fig. 4. Dependencies of current densities of electron beam (1) and ion beam (2), discharge current (3), charged particle currents to the flat (4) and cylindrical (5) cathodes on a potential difference between cathodes *DU*. U_a = 1,5 kV, *Í* = 600 Oe, $Ð = 9\cdot 10^{-5}$ Torr.

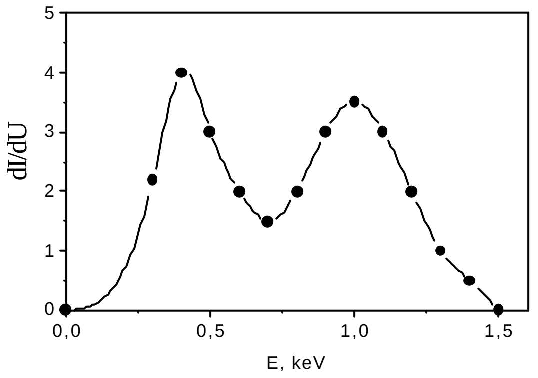

Fig. 5. Ion energy distribution.
U_a = 1,5 kV, Í = 600 Oe, *DU* = 80 V, Ð = 9·10^{-5} Torr.

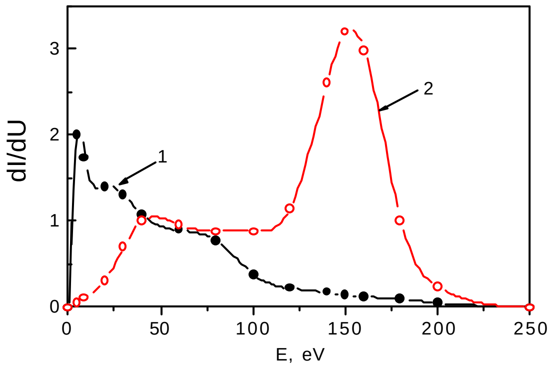

Fig. 6. Electron energy distribution.
U_a = 1,5 kV, Í = 600 Oe, Ð = 9·10^{-5} Torr.
1 - *DU* = 80 V, 2 - *DU* = -150 V.

The optimal location of a treated surface was determined with help of the flat collector 6. As seen from Fig. 7, at *DU* = 80 V both the total current of charged particles to the collector (curve 1) and the floating potential of collector (curve 2) become zero at the distance 1 cm from internal end of cylindrical cathode 5. In this region the radial inhomogeneity of current compensation degree of an ion beam did not exceed 5% ÷ 10%. The removing of the collector from cathode 5 was resulted in increasing the negative values of current to the collector and its floating potential. It seems this behavior is responsible for the large radial component of an ion velocity. Consequently, the ions leaves the beam, when collector is removed from cathode. The current efficiency of the ion source with the optimal value *DU* = 80 V was 10% - 15%.

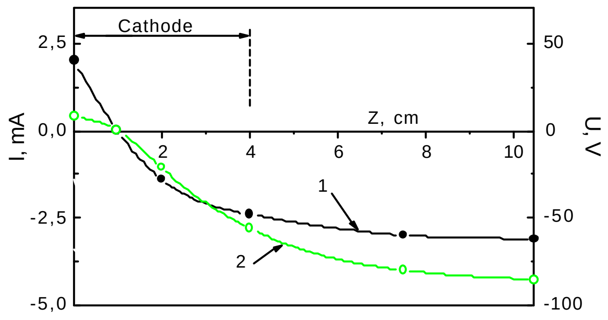

Fig. 7. Distribution of current to collector (1) and floating potential of collector (2) along system axis.
U_a = 1,5 kV, Í = 600 Oe, *DU* = 80 V, Ð = 9·10^{-5} Torr.

Conclusions

The possibility of compensated ion beam generation from electrically unsymmetrical source with oscillating electrons was experimentally investigated.

The spatial location of ion beam compensation region, optimal values of operating pressures and potential difference between cathodes were determined.

The way to control the degree of current compensation of the ion beam by varying a potential difference between cathodes was found.

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