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ON THE POSSIBILITY OF FORMING COMBINED BEAMS OF CHARGED PARTICLES IN A PLASMA SOURCE BASED ON A DISCHARGE IN CROSSED E×H FIELDS

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In this work, the experimental electrode structure of a plasma electron-ion source for the joint formation of electron and ion beams is proposed, a number of characteristics are given, and the prospects for further development of an electron-ion source for industrial application on its basis are shown

Keywords: plasma source of charged particles, electron-ion influence, electron beams, compensated ion beams.

Introduction. Sources of ion and electron beams make it possible to realize an extensive cluster of modern innovative technologies for processing, modifying, and creating new materials. In some cases of such technologies, a significant increase in their quality and equipment performance is possible when implementing simultaneous exposure to electron and ion beams. Currently, this technology is usually provided using separate electron and ion sources. In this case, gas-discharge electrode structures, in which magnetron discharges are excited, [1, 2] are the most widely used for the formation of plasma surfaces emitting ion or electron beams, or discharges with oscillations of Penning type electrons (PIG) [3] or with a hollow cathode [4, 5]. Under technologically necessary conditions of low gas pressure, thermal cathodes are used to reduce the discharge voltage and the density of the emitting plasma in gas-discharge structures [6]. However, this is a drawback of sources, due to the low durability of thermal cathodes in gas discharges.

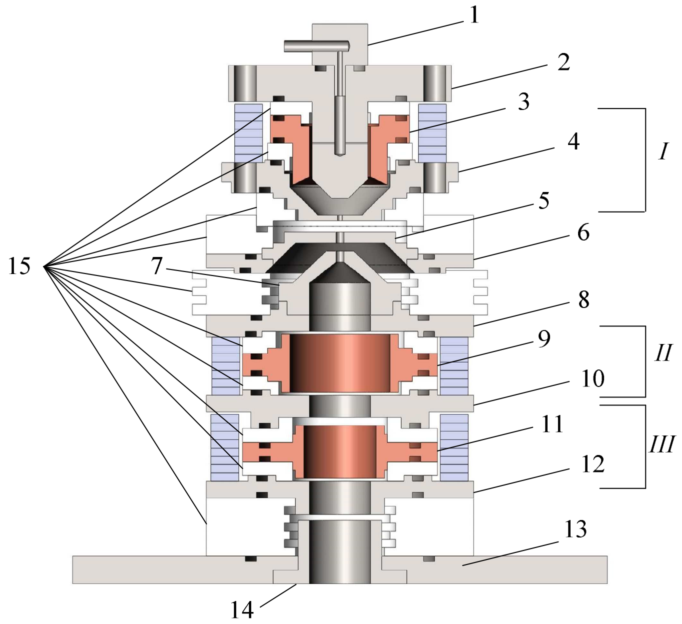
In these discharges, the emitting plasma is separated from the electrodes of the gas-discharge structure by near-wall electric layers, the parameters of which are determined by the potential difference between the plasma and each electrode, as well as the plasma density, as is accepted (at present) by the condition that the electric field strength at the plasma boundary is equal to zero [7] . The emitting plasma surface, as is customary, also obeys this condition [8]; therefore, the electron (ion) optical conditions in the interval of electron (ion) acceleration and beam formation depend on the position and shape of the emitting plasma boundary, i.e. on accelerating voltage and electrode geometry and their potential. This creates certain difficulties in the formation of large section beams [9].

However, the well-known [10] effect of the possible formation of a secondary plasma in the accelerating gap can provide a significant improvement in the emission-optical properties of a source with a plasma emitter: a decrease in the beam divergence due to a decrease in the radial potential gradient in the accelerating gap; increase in emission current due to the reverse flow of charges from the secondary plasma into the emitting plasma [11]; as well as increasing the perveance of the accelerating system due to the partial compensation of the space charge of the beam.

The foregoing suggests the following. First, the possibility of creating a plasma object with electrostatic layers in it, capable of ensuring the formation of ion and electron beams combined in a single space. Secondly, the multifactorial nature of such a structure and the lack of necessary algorithms currently complicate the numerical simulation of such structures. Thirdly, the experimental study of such structures at this stage seems to be most effective for creating technological sources of combined ion-electron beams.

In this paper, we propose a concept and a design developed on its basis for a single multi-discharge structure that is capable of forming combined or alternating ion-electron beams, as well as some experimental results of the formation of such beams.

Physical concept and electrode structure of the experimental source . A sketch of the electrode structure of the developed model of the electron-ion source is shown in Fig. 1. The model is an emitting plasma generator formed in a volume limited by the inner surfaces of cathodes 2 and 4, anode 3, and emitter electrode 5 (discharge chamber I). Electrodes 6 and 7 form an electron acceleration gap where a plasma surface is formed that emits electrons. Electrodes 8-12 form a gas-discharge structure forming a plasma, which is a source of atomizing ions. This structure consists of two "Penning" type discharge cells (II and III) connected in series (along the axis) [3]. Elements of this structure 9 and 11 are the anodes of the discharge cells; elements 8, 10 and 12 - cathodes, which are simultaneously pole tips of permanent magnets. It can be assumed that in these cells, both the electron oscillation between the cathodes and the similarity of their cycloidal motion, realized in magnetron-type discharges, are provided [12, 13].



1 – fitting for plasma gas inlet; 2 – internal cathode; 3 – the main anode; 4 – external cathode;
5 – emitter electrode; 6 – auxiliary anode; 7 – accelerating electrode; 8, 10, 12 – cathodes; 9, 11 – anodes;
13 - flange for mounting the structure on the working chamber; 14 – matching electrode; 15 – insulators;
I, II, III – areas of discharge chambers

Figure 1. - Appearance and internal structure of the developed layout electron-ion source with crossed E × H fields

At the same time, the magnetic field generated by the cathodes 8, 10 and 12 forms a magnetic focusing system for an accelerated electron beam propagating along the axis of this (second) gas-discharge structure until the ion-electron beam exits the source into the process chamber. A voltage is applied between the electrodes 12 and 14 that accelerates the ions to the ion energy required by the technology. At the same time, in this gap (between the electrodes 12 and 14), the beam of electrons accelerated in the gap between the electrodes 6 and 7 is decelerated. The ion emitting plasma surface formed between the electrodes 12 and 14 determines the paths of both ions and electrons in space drift of the electron-ion beam to the sputtered target, and therefore determines the distribution of the density of ion and electron currents on the surface of the target.

Each discharge chamber of a single structure has an independent power supply and acceleration system, which allows the formation of various operating modes of the entire source as a whole.

Figure 2 shows the current-voltage characteristics of extraction during the simultaneous formation of an electron beam (discharge chamber I, Fig. 1) and ions (discharge chambers II and III, Fig. 1) for two modes: a fixed voltage of the unit accelerating ions at the level of 1.5 kV and variation the electron accelerating voltage and the second mode of operation, when the electron accelerating voltage was recorded, and the ion accelerating voltage was varied.

In the case of a fixed ion accelerating voltage in section I (curve 1, Fig. 2), almost complete compensation of the electron beam is realized in the range from 0 to 1.5 kV and the current into the Faraday cup is close to zero. When the electron accelerating voltage exceeds +1.5 kV (a fixed value of the ion accelerating voltage -1.5 kV), the current in the Faraday cup rises, but it (region II on curve 1, Fig. 2) is lower than the value of the emission current obtained in this structure when initiating a discharge in the discharge chambers I and II and the supply of accelerating electrons voltage.

When the electron acceleration voltage is fixed at +1.5 kV and the ion acceleration voltage is varied (region I, curve 2 in Fig. 2), the current into the Faraday cylinder undergoes an abrupt change in polarity in the voltage region of 1.5 kV (Fig. 2, curve 2), which indicates the mutual compensation of the electron and ion beams to this value and the prevailing emission from the ion source at voltages above 1.5 kV. The ion emission current at a voltage of 3 kV is 45 mA, and the ion emission current density is about 10 mA/sm^2, which indicates the prospects of developing an electron-ion source based on this design for the industrial implementation of various processing technologies and surface modification of materials.

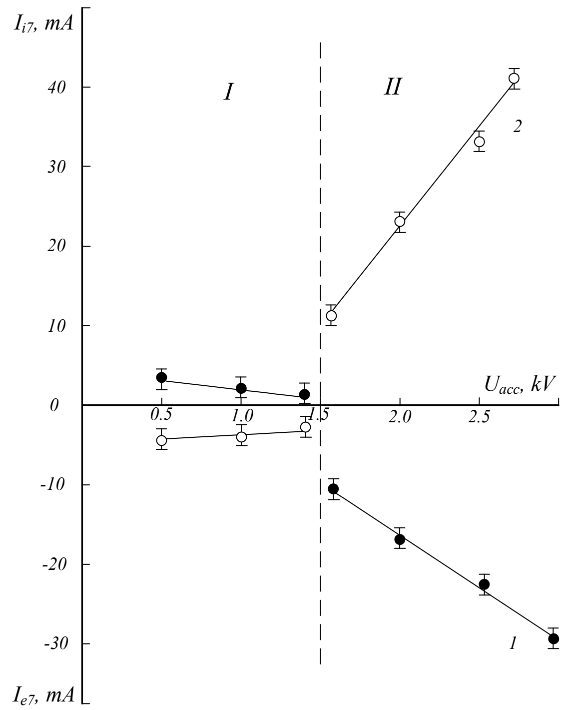


Figure 2. - Current I_7 (into the Faraday cylinder). I_{e7} is the electron current in the Faraday cylinder. I_{i7} is the ion current in the Faraday cylinder.

(1) fixed ion acceleration voltage of 1.5 kV.

(2) fixed electron acceleration voltage of 1.5 kV.

The discharge current in chamber I (Fig. 1) is 200 mA, and the burning voltage of the discharge is 420 V. The discharge current in chamber II (Fig. 1) is 180 mA, and the discharge voltage of the discharge is 410 V

It should be noted that in Figure 2, in region I, there is an area of uncertainty in the polarity of the emission current, which is apparently caused by the presence of double electric layers in the discharge structures II and III (Fig. 2). At accelerating voltages of more than 1.5 kV in region II (Fig. 2), the field of double electric layers already has a weak effect on the movement of charges in gas-discharge structures II and III (Fig. 2), and the currents of electrons I_{e7} and ions I_{i7} (Fig. 2). 2) have certain values.

The experiments were carried out in a wide range of gas inlets (1.1-3.5) mPa·m^3/sec and discharge currents (0.18-0.24) A. The characteristics were similar to those presented and are not shown in the figures. The linear form of current-voltage characteristics provides high controllability of the technological characteristics of the source. The presence of additional discharge structures and corresponding power supply systems, of course, complicates the design of the source, however, the uniqueness of the influence of voltage in additional power supplies on the extraction characteristics of the source as a whole allows you to create a common coordinated automated control system. The above characteristics indicate the possibility of developing a technological source of charged particles for the implementation of technologies that require combined exposure to electron and ion beams.

Conclusion. The presented design of a plasma source of charged particles are far from exhausting the whole spectrum of possible technological and constructive solutions, but only shows the potential possibilities of this type of sources for solving urgent problems of forming technological combined electron and ion beams for implementing electron-beam assisting by plasma-chemical processes or combined exposure to electron and ion beams. Although the tests performed showed the promise of the developed design for implementing the regimes of electron beam formation with an increased perveance and the formation of joint electron-ion beams, the capabilities of the developed structure are not limited to these operating modes. The proposed design can serve as a prototype for the creation of technological sources for the formation of compensated ion beams,

beams of neutral atoms, or for the implementation of alternating or simultaneous exposure to beams of both types of charged particles. Such sources can become a unique universal tool for applying film coatings for various purposes [11-13]. Such systems may be of interest as individual sources, as well as cells of a multi-bit source for forming an effect on large areas.

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