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PLASMA SOURCE OF CHARGED PARTICLES BASED ON A DISCHARGE IN CROSSED E×H FIELDS WITH AN INCREASED PERVEANCE

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This paper presents a design layout of the plasma source of charged particles in crossed E×H fields with high perveance. Its electrode structure is given, describes a source operation mechanism, the prospects for further development of a high-perveance source for industrial applications based on it are shown.

Introduction. The accumulated experience of using sources of charged particles [1-3] indicates the prospects of their use for the implementation of combined resource-saving technologies for processing surface layers, product engineering and the formation of composite coatings on materials. The creation of new constructions of sources with a plasma emitter for the implementation of combined resource-saving technologies for electron-ion-plasma processing of surface layers based on them will reduce energy costs, as well as improve the operational characteristics of products. To solve this problem, it seems promising to develop high-performance sources of low- and high-energy (depending on the field of application) beams of charged particles.

It should be noted that the perveance P is a measure of the intensity of the flow of charged particles and characterizes the effect of space charge on the beam of charged particles, it is equal to the ratio of the particle beam current to the equivalent accelerating voltage at this point to the extent of three second: $P = \frac{I}{U^{3/2}}$ [4].

The modern theory and experience of using plasma sources of ion and electron beams show that diode structures with plasma charge emitters automatically provide enhanced perveance at a given emission current density [5]. This is due to the impossibility of forming a Langmuir potential minimum near the plasma emitter due to the possibility of simultaneous emission of both electrons and ions from the plasma [6]. This possibility leads to an automatic movement of each element of the surface emitting plasma to implement zero potential gradient conditions on the entire surface. Thus, a diode with a plasma emitter operates in saturation mode when the emission current is equal to the current of the anode of the diode gap.

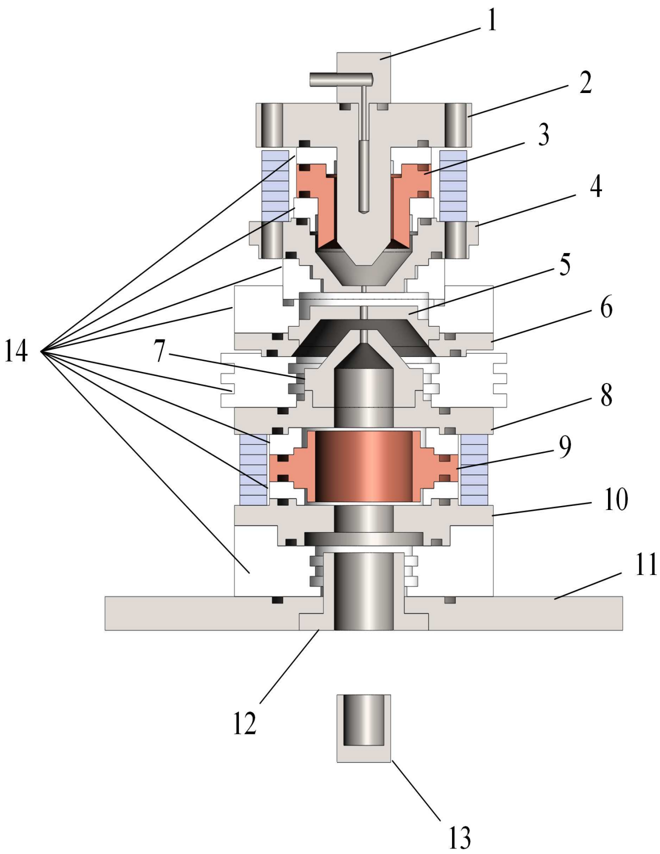
A further increase in perveance in a diode with a plasma emitter is possible due to compensation of the space current charge in the diode (electron or ion) by charges of a different type in the entire diode gap. Such a situation is realized, in particular, in double electric layers arising under certain conditions in a plasma. Such layers can be considered as diodes with a plasma emitter and a plasma anode. The perveance of double electric layers can be considered maximum for a given current density in the layer (diode).

Results and its discussion.

An analysis of the known designs of plasma sources of charged particles (electrons) and the basic physical processes in them shows that it is possible to modify these structures in order to create more effective conditions for the plasma formation and to obtain an emission current, without significantly complicating the design and changing the power supply systems. This paper presents a design layout of the plasma source of charged particles in crossed E × H fields with high perveance of the electrode structure of which is shown in Figure 1.

The mechanism of the proposed design is as follows. Plasma, through a part of the surface of which the electrons selection (emission) is carried out, is formed in a volume limited by the internal surfaces of the cathode 2, the reflective cathode 4, the main anode 3 and the emitter electrode 5. These electrodes are separated by insulators. Cathodes 2 and 4 are the tips of a permanent magnet, creating a magnetic field between them, which contributes to the oscillation of secondary electrons from the cathodes into the plasma formation space. Electrodes 5, 6, and 7 form an electron acceleration gap where a plasma surface that emits electrons is formed. Electrodes 8–10 form a gas-discharge structure that forms a plasma, which is a source of ions. This structure is a Penning type cell

[8]. At the same time, the magnetic field generated by the cathodes 8, 9 forms a certain magnetic focusing system for an accelerated electron beam propagating along the axis of this gas-discharge structure until it leaves the source in the process chamber.



1 – plasma gas inlet channel; 2 – cathode; 3 – main anode;
4 – reflective cathode; 5 – emitter electrode; 6 – auxiliary cathode; 7 – accelerating electrode; 8, 10 – cathodes; 9 – anode; 11 – flange for mounting the structure to the working chamber; 14 – insulators

Figure 1. – Appearance of the developed source layout with increased perveance

The electrodes of the developed model of the electron source are connected to the power supply system separately, each discharge structure has its own discharge power supply. It was assumed that the relationship of separately controlled discharges in the structure will contribute to an increase in the degree of gas ionization at reduced pressure. The mechanism of operation, which provides an increase in perveance, is as follows: the electron beam formed in the upper chamber (electrodes 2-5, Fig. 1) after acceleration enters the structure formed by the electrodes of the lower chamber (electrodes 8-10 Fig. 1), where a low-pressure discharge forms a plasma emitting ions. The generated electron beam, propagating along the axis in this structure, increases the degree of plasma ionization in this discharge. Ions propagate into the upper structure, increase gas ionization in the electron selection region and the emission current density, and partially compensate for the electron space charge in the accelerating gap, which generally leads to an increase in the source perveance.

The implementation of this mechanism is evidenced by a change in the slope of the current-voltage characteristics of extraction in the presence (Fig. 2, curves 4-6 and Fig. 3, curves 3-5) of discharge initiation in the lower discharge chamber (electrodes 8-10 of Fig. 1) in comparison with its absence (Fig. 2, curves 1-3 and Fig. 3, curves 1, 2). The type of characteristics indicates a weak effect on the source perveance of the discharge current and gas inlet (pressure in the discharge chamber) in the working range of the stable existence of the discharge. From the presented characteristics it is seen that the determining effect on the source perveance is exerted by the presence of an additional discharge in the lower discharge chamber (electrodes 8–10 of Fig. 1).

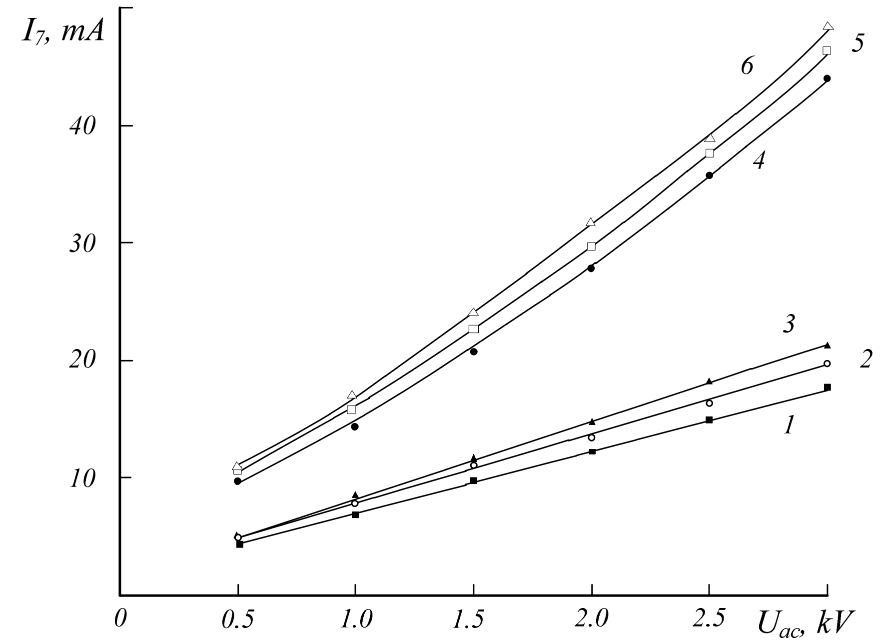


Figure 2. – Current I_7 (into Faraday cylinder) in the absence of (1-3) and the presence (4-6) discharge initiation in the lower discharge chamber (electrodes 8-10, Fig. 1) for various gas inlets *Q*:

I_d in the upper chamber (electrodes 2-5, Fig. 1) 200 mA, discharge voltage 420 V;

I_d in the upper chamber (electrodes 8-10, Fig. 1) 180 mA, discharge voltage 410 V.

Gas inlet *Q*: 1, 4 – $0{,}05\cdot10^{-4}$ l/sec; 2, 5 – $0{,}1\cdot10^{-4}$ l/sec; 3, 6 – $0{,}38\cdot10^{-4}$ l/sec

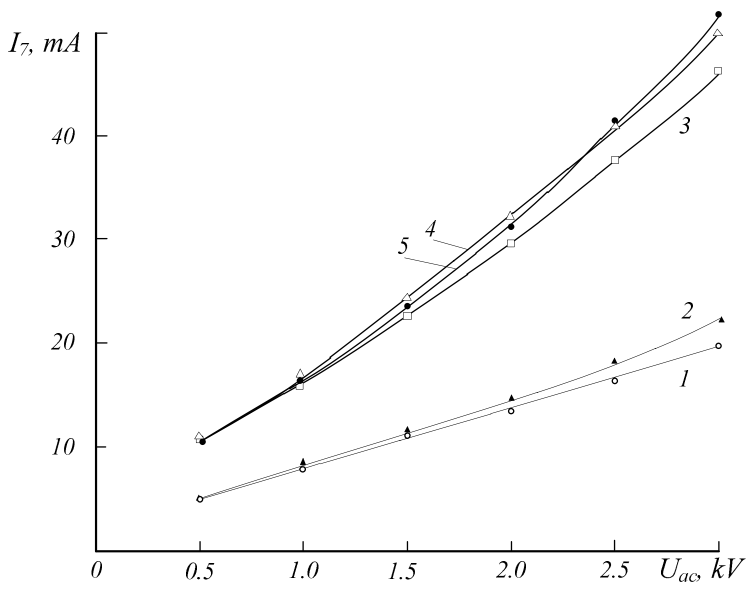


Figure 3. – Current I_7 (into Faraday cylinder) in the absence of (1-2) and the presence (3-5) discharge initiation in the lower discharge chamber (electrodes 8-10, Fig. 1) for various discharge currents in the upper and lower chambers:

1-5 – gas inlet Q – $0{,}1\cdot10^{-4}$ l/sec;

I_d in the upper chamber (electrodes 2-5, Fig. 1) 1, 3, 5 - 200 mA, discharge voltage 420 V; 2, 4 – 240 mA, discharge voltage 450 V;

3, 4 - I_d in the lower chamber (electrodes 8-10, Fig. 1) 180 mA, discharge voltage 410 V; 5 - I_d in the lower chamber (electrodes 8-10, Fig. 1) 210 mA, discharge voltage 430 V.

Gas inlet *Q*: 1, 4 – $0{,}05\cdot10^{-4}$ l/sec; 2, 5 – $0{,}1\cdot10^{-4}$ l/sec; 3, 6 – $0{,}38\cdot10^{-4}$ l/sec

Conclusion. Along with known methods that increase the switching of the electron current from plasma to the accelerating gap (emission current) in plasma sources of charged particles, a significant increase in the perveance of plasma sources of both high-energy and low-energy beams is provided by filling the electron-accelerating gap with ions that compensate for the space charge of the electron beam. Moreover, to increase the perveance of plasma electron sources in a continuous mode, it is advisable to use an accelerating electrode in the form of a plasma surface that accelerates electrons and, at the same time, emits ions into the gap accelerating electrons. For this, the accelerating electrode must be an element of the electrode gas-discharge structure forming the plasma. Between the electron-emitting plasma and the plasma of the accelerating electrode, a double electric layer is formed with a high perveance for the accelerated electron beam.

The obtained results indicate the possibility and prospects of using the developed source for developing a high-perveance source for industrial applications.

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