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Forevacuum plasma electron source of a ribbon electron beam with a multi-aperture extraction system

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Abstract. The article presents the results of using a multi-aperture extraction system in the source of a ribbon electron beam. The optimal size of the holes in the anode and extractor, as well as the distance between the anode and the extractor at which the beam losses are minimal, are investigated.

1. Introduction

Plasma technologies are used for etching and surface cleaning of semiconductors, dielectrics and metals [1-3], and are used in medicine for disinfection and sterilization of instruments [4]. Plasma can be used for the synthesis of biocompatible coatings [5]. As a rule, gas discharges of different frequency ranges are used to create plasma. In addition, it is possible to use an electron beam to create a plasma. When transported in a vacuum chamber, the electron beam ionizes the gas and thus creates a beam plasma. This method of plasma creation has a number of advantages over gas-discharge devices. The size of the plasma directly depends on the cross-section of the electron beam. Plasma parameters can be controlled by changing the parameters of the electron beam and the composition of the gas atmosphere. The formation of a plasma with a ribbon electron beam makes it possible to create a beam plasma with an area of several tens of square cm. [6]. In addition, the electron beam can be injected into almost any gas, as well as gas and vapor-gas mixtures. In this case, nonequilibrium plasma chemical reactions can occur in the plasma volume, including reactions not observed under other conditions. Choosing the type of gas, its pressure, and by changing the conditions of generation of beam-plasma it is possible to achieve a wide range of plasma chemical reactions. The most optimal pressure range for plasma chemical reactions is from 1 to 100 Pa. To create a beam plasma in this range, it is preferable to use the so-called forevacuum electron beam sources, and to form a large-volume plasma, use a ribbon electron beam source. The source of the ribbon electron beam forms an electron beam in the form of a ribbon with an aspect ratio in the cross section of more than 10:1. As a rule, in plasma sources, stabilization of the plasma boundary is carried out using a metal grid. In the case of cylindrical beams of small cross-section, this method works well, because due to the small cross-section of the beam, its homogeneity can be increased. In the case of an extended plasma boundary, as well as in the conditions of heating by a reverse ion flow, the grid can be bent, and the condition of uniformity cannot be fulfilled.

In the so-called multi-aperture extraction systems [7], which are used to generate beams of large cross-section, the electron beam is formed by adding separate beams. Such beams are formed in elementary acceleration cells, which are two or more electrodes with coaxial holes. In such systems, the beam losses on the electrodes are minimal and usually do not exceed a few percent. The coating of the emission (plasma) electrode of a multi-aperture system with a fine-structure grid stabilizes the position of the emission plasma boundary and provides a wider range of parameter changes both in the formation



of ion [8] and electron [9] beams. In the electron source with arc discharge, the multi-aperture system was also used to stabilize the plasma boundary and increase the electrical strength of accelerating gap of the source [10]. In addition, the paper shows that the presence of a mask on the emitter electrode is a condition for stable operation of the electron source. With no mask, the average power of the beam in the acceleration gap was no greater than 3500 W, whereas with a mask placed in the emitter, it could be increased to 6500 W. The use of a multi-aperture system in sources of high-energy electron beams has no alternative and allows to obtain high-power beams of subrelativistic electrons with a cross-sectional area $\sim 10^2$ cm [11]. Such beams are used in a number of scientific and technical applications, particularly, in a material science and engineering, for surface modification of solids, modeling of high thermal fluxes on plasma facing components in fusion reactors, etc. [12]. In addition, the thermal load on the grid is reduced, since it is sandwiched between flat electrodes, the heating of which is much less.

The aim of this work was to study the influence of the parameters of a multi-aperture system on the formation of a homogeneous band electron beam in the forevacuum pressure region.

2. Experimental setup

The experiments were carried out using a forevacuum plasma source of a ribbon electron beam [13]. The scheme of the electron source, as well as its location and measuring instruments are shown in figure 1. The electron source consists of three main electrodes. The flat anode and the extended hollow cathode are the discharge plasma generator. The acceleration of electrons is carried out in the space between the anode and the extractor. The use of a hollow cathode makes it possible to provide conditions for the generation of a high-density discharge plasma, and the small distance between the anode and the extractor (2-10 mm) provides the electrical strength of the accelerating gap.

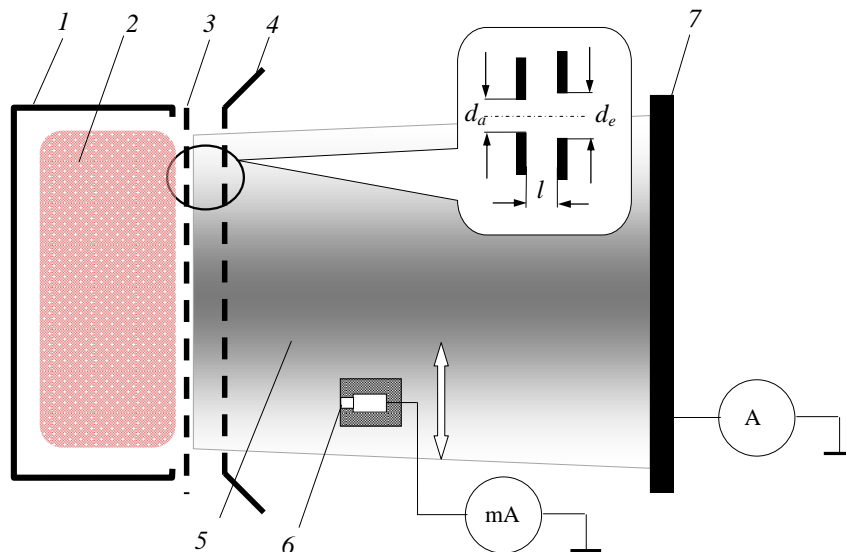


Figure 1. The scheme of the source of the ribbon electron beam and the location of the measuring probe in the chamber: 1 – Extended hollow cathode, 2 – glow discharge plasma, 3 – anode, 4 – extractor, 5 – electron beam, 6 – probe, 7 – beam collector.

The emission window in the anode was covered by a metal plate 1 mm thick containing 50 holes with a diameter $d_a=3.5$ mm located in the middle part of the plate along its long side. The distance between the centers of the holes was 6 mm. In the extractor it was possible to install a removable insert with holes arranged coaxially with each hole of the anode plate. The diameter of the holes in the d_e extractor plate was 3.5 mm, 4.5 mm, 5.5 mm. The distance between the plate in the anode and the extractor l varied from 2.5 mm to 10 mm. The work was carried out in an air atmosphere at a pressure of 7 Pa. The accelerating voltage in the experiments varied from 2 to 8 kV, the discharge current from 200 to 800 mA.

The current density distribution was investigated using a movable collector. The collector had a narrow slit width of 1 mm and allowed to measure the transverse distribution of the beam current density.

3. Experimental results and discussion

The current density distributions measured at a distance of 10 cm from the plane of the electron beam entry into the vacuum chamber are shown in figures 2-4. Since the emission is carried out from a set of elementary holes, the current distribution contains alternating areas with high current density. This form of distribution is obviously associated with incomplete overlap of current flows extracted from the elementary holes.

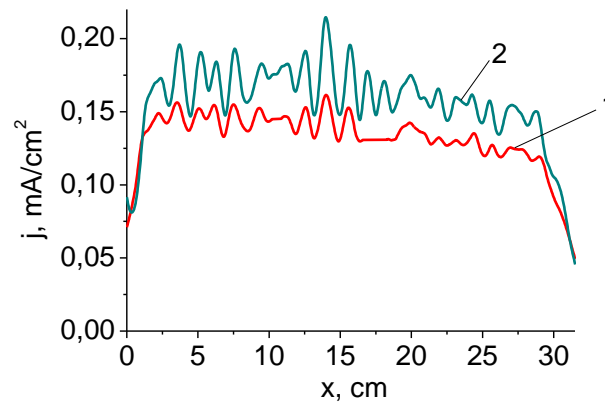


Figure 2 - Current density distribution at accelerating voltage 1 - 2 kV, 2 - 8 kV. Beam current 100 mA, d_a – 3.5 mm, d_e – 3.5 mm, l - 5 mm.

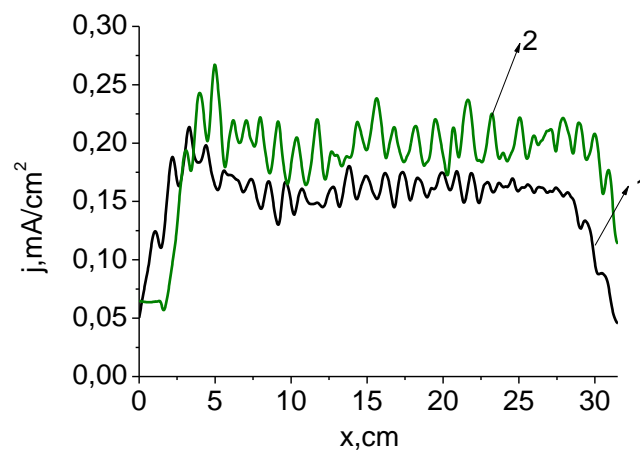


Figure 3 - Current density distribution at accelerating voltage 1 - 2 kV, 2 - 8 kV. Beam current 100 mA, d_a – 3.5 mm, d_e – 4.5 mm, l - 5 mm.

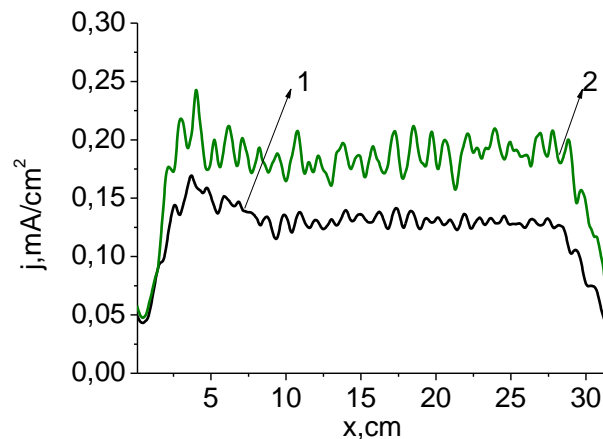


Figure 4 - Current density distribution at accelerating voltage 1 - 2 kV, 2 - 8 kV. Beam current 100 mA, d_a – 3.5 mm, d_e – 5.5 mm, l - 5 mm.

Indeed, at a distance of 30 cm from the plane of injection of the electron beam into the vacuum chamber, the distribution is more uniform, figure 5.

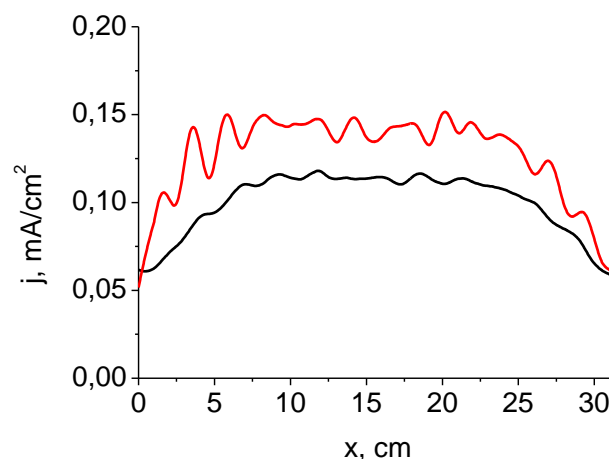


Figure 5 - Current density distribution at accelerating voltage 1 - 2 kV, 2 - 8 kV. Beam current 100 mA, d_a – 3.5 mm, d_e – 3.5 mm, l - 5 mm. The distance from the electronic source is 30 cm.

It should be noted that with the increase in the diameter of the hole, the change in the collector current depends on the accelerating voltage. When the accelerating voltage is low - 2 kV, the increase in the diameter of the hole in the extractor has little effect on the value of the extracted current. With an increase in the accelerating voltage of more than 8 kV, the collector current increases with the diameter of the hole in the extractor. Such an increase in the collector current with an increase in the accelerating voltage can be explained by a change in the configuration of the electric field in the accelerating gap. As the accelerating voltage increases, the divergence of elementary electron beams emitted from individual emission holes decreases. This is due to the reduction of the effect of the initial spread of the velocities of the electrons emitted from the plasma, as well as by reducing the scattering on the molecules of the residual atmosphere and, consequently, reducing the loss on the extractor.

Changing the distance between the plane of the anode and the extractor also affects the value of the beam current. So if you reduce the distance anode-extractor current losses in the extractor is reduced. This is due to the fact that at a smaller distance from the emission boundary, the beam divergence degree is less, and, consequently, the losses on the extractor will also be less. The current measurement of the extractor confirms it (figure 6).

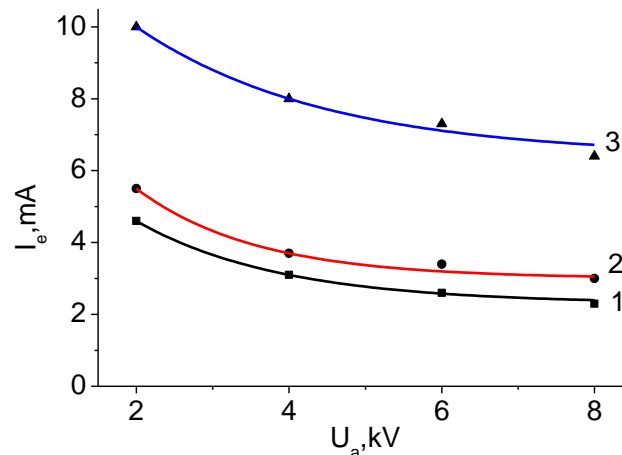


Figure 6 - Dependence of the extractor current on the accelerating voltage for different anode-extractor distances l: 1 – 2.5 mm, 2 - 5 mm, 3 - 10 mm.

Thus, the experiments show that when using a multi-aperture system with a diameter of elementary holes in the anode 3 mm and 5.5 in the extractor and at a distance between the anode and the extractor 2.5 mm losses on the extractor are minimal. The minimum current loss on the extractor indicates a high electron beam current flow and the efficiency of using a multi-aperture system to generate a ribbon beam. The result shows the difference between multi-aperture electron-optical acceleration systems and grid systems. In extraction systems using a grid in the anode, the current-carrying coefficient does not exceed 2/3, which leads to a loss of at least one third of all accelerated electrons on it.

4. Conclusion

Multi-aperture system used to extract electrons in the source of the electron beam, reduces the loss of current on the extractor, and thus increase the current flow. Minimum current losses are observed at an accelerating voltage of 8 kV, for low accelerating voltages the losses are higher due to the influence of the initial spread of electron velocities. The parameters of the multi-aperture system with minimal losses on the extractor are determined.

Acknowledgments

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