Forevacuum plasma electron source for the generation of beam-plasma and beam-plasma discharge

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Abstract: Presents the design and main parameters of the forevacuum plasma electron sources. The sources allow generating beam plasma of different geometry and with high concentration – up to 10^{16} m^{-3}. The modes of generation of the beam-plasma discharge in the medium of various gases at pressures of 5-10 Pa are described. For the first time the regime of beam plasma generation with periodically changing density is described.
Keywords: plasma electron source, beam plasma, forevacuum.

1. Introduction

Traditionally, different types of discharges - glow, arc, microwave discharge, as well as their combinations-are used to obtain a highly nonequilibrium low-temperature plasma [1-3]. Despite the progress made in the application of this method of plasma generation, there are a number of difficulties. The main ones are a rather narrow range of conditions under which there is a steady burning of discharges, the complexity of independent regulation of ion energy, ion current density, the composition of the working gas mixture. [4].

Unlike gas-discharge plasma generators, the use of electron beam injection into the gas medium and the formation of beam plasma due to the processes of ionization of atoms and molecules by beam electrons has a number of advantages. The main difficulties lie in the independence of the parameters of the electron beam from the kind of plasma-forming gas, the possibility of propagation of the electron beam and the creation of plasma in a fairly wide range of pressures [5]. In addition, the electron beam can be injected into the plasma already created by various kinds of discharges, which expands the possibilities of practical application of electron-beam plasma in the operations of modification of materials due to the simultaneous use of two plasma-forming factors. By changing the pressure and composition of the plasma-forming medium, controlling the processes of generation of active particles in the plasma by changing the parameters of the electron beam, a wide range of plasma chemical reactions is achieved [6]. Typically, the electron beam generation region and the region where the beam plasma is generated are two different regions. This separation is due to the complexity of ensuring the efficiency of the electron source at pressures in units and hundreds of Pascals, which are usually installed in the volume occupied by the gas. In this regard, technical solutions are needed to conduct powerful electron beams from vacuum to gas, or devices that allow the generation of electron beams at pressures corresponding to the pressure in the region occupied by the gas. Pressure range of 1-100 Pascal refers to a forevacuum, which is already quite well developed so-called forevacuum plasma sources of electrons [7]. Changing the shape of the emission boundary of the plasma allows such sources to create electron beams of different configurations – focused, wide-aperture and ribbon.

The aim of this work is to study the parameters of the beam plasma generated by the interaction of electron beams of different configurations with the gas atmosphere of the vacuum chamber at pressures of 5-10 Pa.

2. Experimental setup

A schematic representation of the experimental setup is shown in Fig. 1 .

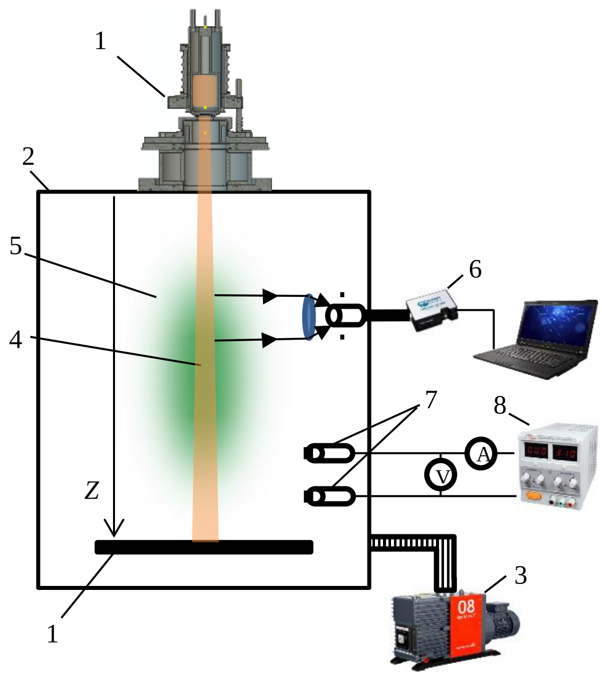

Fig. 1. Experimental setup. 1 – plasma electron source, 2 – vacuum chamber, 3 – forevacuum pump, 4 – electron beam, 5 – beam plasma, 6 – optical spectrometer and computer, 7 – double Langmuir probe, 8 – bias voltage generator.

The forvacuum plasma source 1 of the focused or ribbon electron beam was installed on the vacuum chamber 2. Pumping of the chamber to a pressure of about 2-3 Pa was carried out using a mechanical pump 3 BocEdwards 80M. Working gases helium, nitrogen, argon were injected directly into the vacuum chamber to a pressure of 10 Pa. Visual observations and photographs of the electron beam 4 and the emission of the beam plasma 5 were carried out through a viewing window with a diameter of 20 cm. Optical emission spectra (200-800 nm) were diagnosed using fiber optic cable and spectrometer 6 (Ocean Optics USB2000, USA). Plasma density and electron temperature were measured using a double Langmuir probe 7. The voltage to the probes (±35 V) was supplied by the generator 8. Measurement of the voltage drop between the probes, as well as the current flowing in the circuit of one of the probes was carried out using a digital storage oscilloscope Tektronix 2024B. Processing of the probe characteristics was carried out according to the standard technique [8]. The displacement device is allowed to move attached to it the equipment along the beam in the range of 32 cm, thus there was the possibility of studying the spatial distribution of beam-plasma parameters along the section of transportation of the electron beam.

3. Results and discussion

As shown by experiments in the injection of an electron beam into a vacuum chamber, the formation of a beam plasma occurs. The plasma concentration depends on the distance to the electron source and the electron beam axis. Figure 2 shows the concentration distribution along the z-axis. Near the electron source, the concentration is maximal and monotonically decreases as the electron beam propagates through the vacuum chamber. Curves with numbers 1, 2, 3 correspond to the concentration distributions measured at different distances from the beam axis. As expected, the plasma concentration is maximal on the beam axis and also decreases monotonically on the beam periphery.

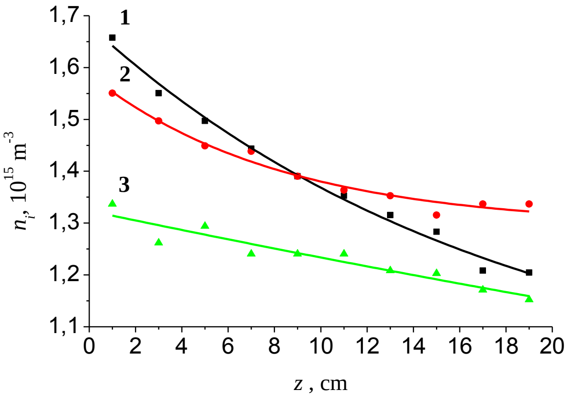

Fig. 2. The dependence of the beam-plasma density n of length of the moving *Z* for different distances from the beam axis: 1 - 1 of cm; 2 - 3cm; 3 - 5 cm. Accelerating voltage Ua = 3 kV and a pressure p = 10 Pa.

In addition to the mode of beam plasma generation with a monotonic plasma density distribution, there are modes in which the concentration depends significantly on the parameters of the electron beam. Thus, with an increase in the beam current density in the crossover region, a more intense glow of the beam plasma is observed. The increase in brightness is a consequence of the increase in plasma density. Changing the position of the beam crossover allows you to move the area with high plasma density, Fig. 3.

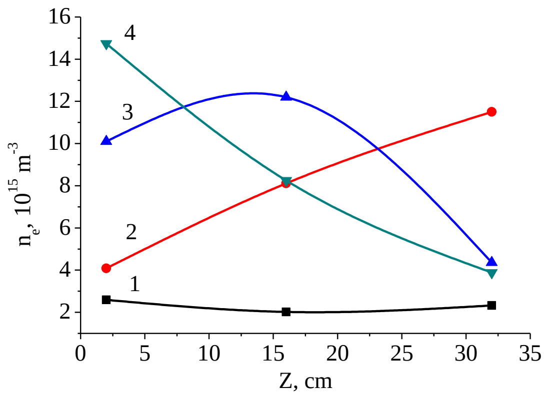

Fig. 3. Distribution of the plasma density along the beam for the accelerating voltage of 8 kV, and at different locations of the region with high brightness: 1 - without glow, 2-glow near the collector, 3-glow in the Central part of the beam transport area, 4-glow near the electron source.

In a very narrow range of electron beam parameters, there is a regime where areas with high plasma concentrations alternate with areas of lower concentration. A photo of this phenomenon is shown in Fig. 4.

Fig. 4. Photo of the beam plasma glow. Beam current 200 mA. Accelerating voltage 10 kV.

It was not possible to experimentally measure the concentration distribution in this case, since the probe introduces large perturbations in the positions of areas with varying concentrations. The plasma density distribution was measured by an indirect method using an optical spectrometer. Figure 5 shows a typical spectrum of helium beam plasma at a vacuum chamber pressure of 40 Pa.

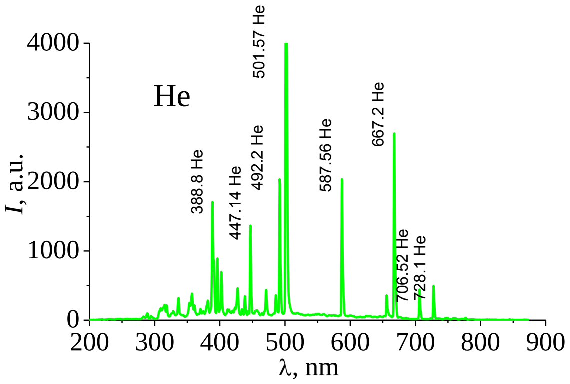

Fig. 5. Typical optical spectrum of helium beam plasma.

Distribution of the most intensive line for the same modes as in Fig. 3 shown in Fig. 6. The same figure shows the intensity distribution corresponding to figure 4.

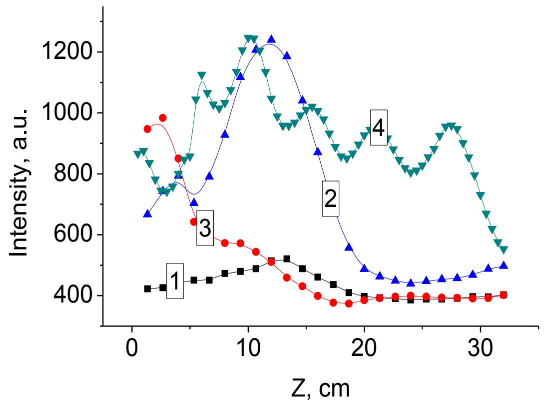

Fig. 6. The intensity of the 501 nm line of helium beam plasma depending on the distance from the electron source and at different locations of the region with high brightness: 1 - without glow, 2 - glow in the central part of the beam transport area, 3 - glow near the electron source, 4 - dark and bright bands in the beam-plasma glow.

As shown in Fig. 6 curve 4 contains alternating minima and maxima, which coincide qualitatively with the position of the glowing areas shown in Fig. 4. In the region of the maximum concentration of the beam plasma exceeds 10^{16} m^{-3}, which allows it to be used for plasma chemical technologies. In addition, the ability to control the position of the region with the highest concentration makes this method of creating a plasma more flexible and versatile in the processing of extended products.

4. Conclusion

The paper presents distribution of the concentration of the beam plasma generated by the plasma electron source in the forvacuum pressure region. It is shown that there are modes of high-density plasma generation. In addition, the position of the region with high concentration can be controlled by changing the position of the beam crossover. The regime of plasma generation with alternation of regions with high and low concentration was also found. This mode of plasma generation is described for the first time and requires further investigation.

5. Acknowledgments

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