Generation of Electron Beam Plasma inside the Dielectric Tube

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The results of experimental study of electron beam plasma inside the dielectric tube are presented. Beam plasma was generated by the fore-vacuum plasma electron source at (2-10) Pa in dc mode. It is shown, that the dependence of the plasma potential on gas pressure inside the tube is completely different in comparison with similar dependence without a tube. Monotonic dependence of the insulated beam collector potential in the tube on beam energy has two stages: slow and fast growth.

Keywords: electron beam plasma, fore-vacuum plasma electron source, dielectric tube

1 INTRODUCTION

Electron beams generated by fore-vacuum electron sources, based on plasma cathode [1], have been employed successfully for a variety of applications, including electron beam welding of ceramic to metal [2], treatment and modification of the surface properties of non-conductive materials [3]. Plasma electron sources have many advantages, such as high emission current density, durability and possibility of working in aggressive atmosphere. In the pressure range (1-100) Pa the electron beam forms beam plasma, which neutralizes the charge brought by the beam to the insulated target. This effect makes it possible to treat dielectric materials. Electron-beam-produced plasma can be of particular interest because of its properties (density, electron temperature) [4], which could be easily regulated by electron beam parameters. Despite the interest in beam plasma, there are no published papers devoted to the generation of electron beam-produced plasma inside the dielectric containers, although the creation of such plasma inside the container looks attractive for plasma chemistry and sterilization.

The purpose of this paper is to show the possibility of beam plasma generation inside the cylindrical dielectric tube and present some special features of such plasma.

2 EXPERIMENTAL SET-UP

The experimental set-up is shown in Fig.1. The set-up consists of a fore-vacuum plasma electron source 1, positioned on the top of the vacuum chamber 2. The electron beam 3 was extracted from gas discharge plasma, which was formed in the hollow cathode by applying the discharge voltage U_d = (400-600) V with the discharge current I_d = (50-200) mA.

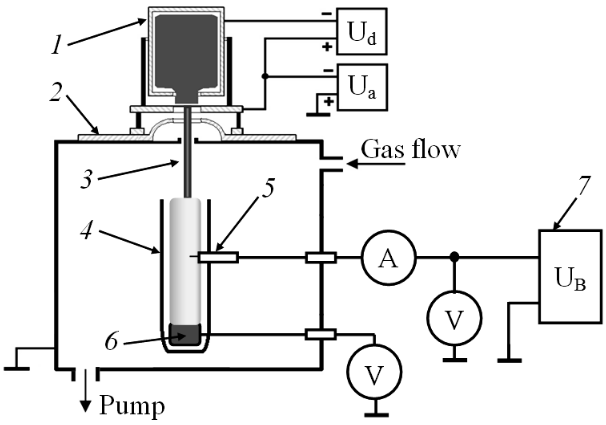

Fig.1: Experimental set-up: 1 – plasma electron source, 2 – vacuum chamber, 3 – electron beam, 4 – quartz tube, 5 – Langmuir probe, 6 – collector, 7 – power supply of bias voltage

The focused beam was accelerated by U_a voltage to the energies up to 12 keV. The vacuum system was maintained by ISP-1000C fore-vacuum pump. A gas flow controller was used to keep the gas pressure (air) at (2-10) Pa. Special experiments were carried out in high vacuum installation at 0.01 Pa, the beam was formed by the electron source of similar design. A quartz cylindrical tube 4 with 20 cm length, 2 mm wall thickness and 4 cm inner diameter was placed along the beam line. The electron beam generated plasma inside the tube and then reached collector 6. The plasma potential φ_p was measured by probe 5, mounted outside the beam and protected by metal screen. The collector potential φ_c was measured by Mastech M-890D voltmeter in dependence on accelerating voltage U_a.

3 RESULTS AND DISCUSSION

The results of collector potential measurements are shown in the Fig.2.

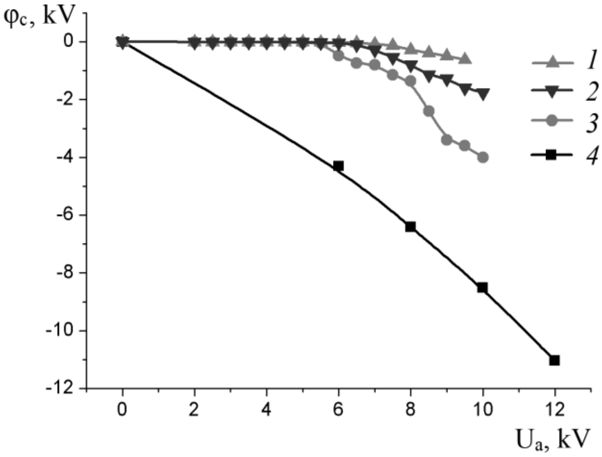

Fig.2: The collector potential as function of accelerating voltage, in fore-vacuum (1-3) and high vacuum (4): 1 – 7.5 Pa, 2 – 4.5 Pa, 3 – 2 Pa, 4 – 0.01 Pa. Beam current I_b = 20 mA

As can be seen, the floating potential of insulated collector depends both on accelerating voltage and pressure. At the lowest pressure of 0.01 Pa the potential φ_c is very close to accelerating voltage. On the contrary, at 7.5 Pa the φ_c value does not exceed 5% of U_a. This fact means that up to 95% of beam energy could be delivered to the collector and without any essential energy losses in interaction with plasma in the beam line. Curves 1-3 in Fig.2 have two stages. The first stage at U_a lower than 5 kV is characterized by weak dependence φ_c on U_a. At higher U_a the absolute value of φ_c strongly increased. The observed φ_c behavior is accompanied by different plasma lighting. The color of lighting is brightly red at the first stage, and faintly violet at the second stage. The observed effects could be connected to ignition of beam-plasma discharge at low accelerating voltages and disappearance of this discharge at higher voltages. The plasma potential φ_p as a function of pressure is presented in Fig.3. This data were obtained when the probe was fixed, and the tube could be removable. We should note that the effect of pressure on the beam plasma potential is quite different for both cases. In case when plasma is closed inside the tube, φ_p has more negative value and it rapidly increases with pressure growth. In our opinion, it occurs due to accumulation of the beam-produced plasma electrons in the tube.

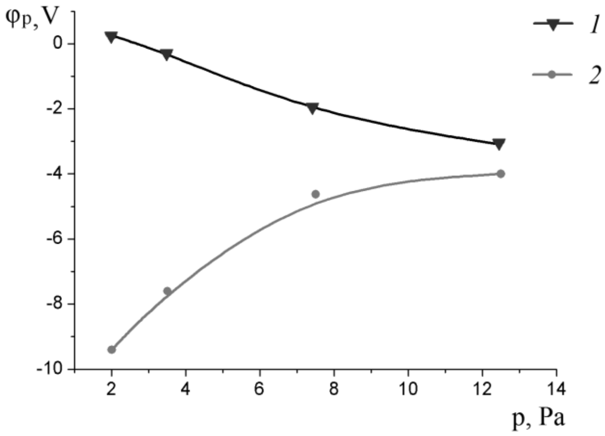

Fig.3: Effect of pressure on beam plasma floating potential: 1 – without the tube, 2 – inside the tube. Experimental conditions: U_a = 3 keV, I_d = 200 mA, U_d = 460 V, I_b = 60 mA

On the contrary, φ_p decreases with pressure growth, when the tube is removed. It occurs due to obstructing the escape of electrons from the plasma volume because of collisions with gas molecules.

3 CONCLUSION

In pressure range (2-10) Pa the electron beam is capable of propagating in the dielectric tube and generating plasma in it. Plasma potential in the tube is more negative than without it.

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