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SHORT COMMUNICATIONS

Generation of a Beam Plasma by a Forevacuum Electron Source in a Space Bounded by Dielectric Walls

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Abstract—A forevacuum plasma electron source is used to generate a beam plasma and measure its parameters in a cylindrical thin-walled quartz bulb. Differences in the gas pressure dependences of the plasma concentration and potential are found when the plasma-generating beam is injected into the dielectric bulb and propagates in an unbounded space.

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INTRODUCTION

Marked interest is today observed in processing the inner surfaces of bulbs and different containers made of insulating materials (polymers, ceramics, glass, etc.) [1]. Ion–plasma modification [2] seems to be a very efficient method to solve such problems. Here, the plasma is usually generated with an electrodeless rf discharge in a space bounded by dielectric walls [3]. Discharges of this type not only offer a number of advantages but also suffer from disadvantages, the main of which are a low efficiency of energy transfer to the plasma, an insufficient power, and a limited range of working pressures. The use of an accelerated electron beam to generate a plasma to a great extent eliminates the disadvantages characteristic of the rf discharge. Nevertheless, as applied to hollow dielectric products, the the electron-beam generated plasma has not yet been considered as a real alternative to techniques currently used. Presumably, this is because the transport of an electron beam inward a dielectric cavity is a challenging task because of charge accumulation on the surface of the workpiece. When the electron beam propagates in a high-pressure (1–100 Pa) range, this influence is mitigated owing to a dense plasma generated in the beam transport region and neutralizing the charge of the dielectric. This range of working pressures is now typical of so-called forevacuum plasma sources of electrons [4]. Our previous investigations [5] showed that in the case of the electron-beam modification by forevacuum plasma sources, the conductivity of the workpiece is of no concern. The feasibility of the electron-beam processing of nonconducting ceramics [6] has stimulated research on using forevacuum plasma electron sources for beam plasma generation inside a dielectric container. The results are presented in this work.

EXPERIMENTAL

The experimental setup is depicted in Fig. 1. A hollow-cathode glow discharge was used in plasma electron source *1* custom-designed for the forevacuum pressure range to generate an electron beam [7]. The source was mounted on the flange of vacuum chamber *2*, which was evacuated by an ISP-1000C mechanical spiral pump to a pressure of 1–15 Pa. Air served as a working gas. Voltage U_d = 450–500 V was applied to initiate a self-sustained hollow-cathode glow discharge. Continuous electron beam *3* with a current of 10–30 mA was extracted from the discharge plasma and accelerated by voltage U_a reaching 12 kV. The diameter of the beam was 5–10 mm.

The accelerated electron beam was injected into cylindrical thin-walled quartz bulb 4 200 mm long and 40 mm in inner diameter. The plasma parameters were measured with single Langmuir probe *5*, whose poten-

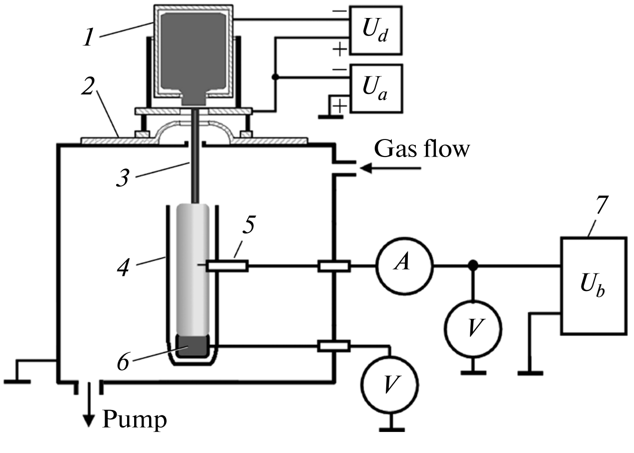

Fig. 1. Experimental setup: (*1*) plasma electron source, (*2*) vacuum chamber, (*3*) electron beam, (*4*) quartz bulb, (*5*) probe, (*6*) collector, and (*7*) bias source.

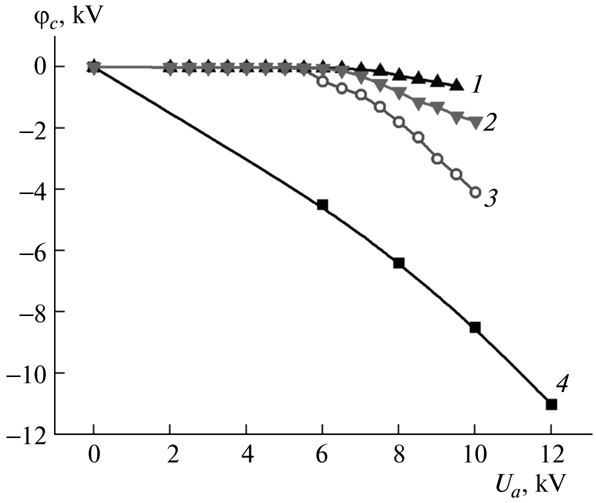

Fig. 2. Potential φ_p of the isolated collector vs. accelerating voltage U_a for a pressure of (*1*) 8, (*2*) 4, (*3*) 2, and (*4*) 0.01 Pa. The beam current is $I_b = 20$ mA.

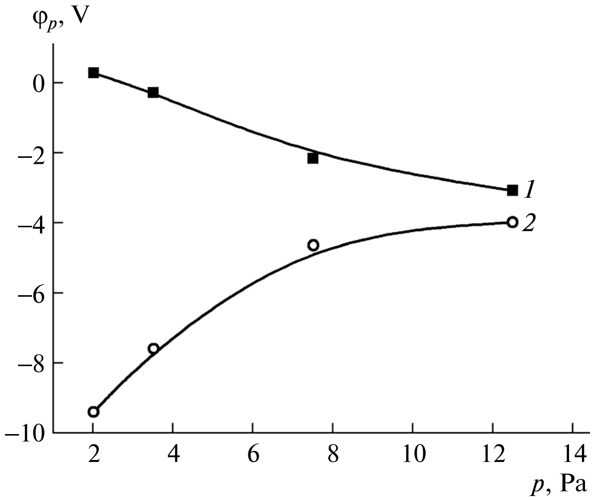

Fig. 3. Langmuir probe floating potential vs. the gas pressure for the electron beam (*1*) propagating in an unbounded space and (*2*) injected into the bulb. The accelerating voltage is $U_a = 3$ kV, $I_b = 20$ mA.

tial relative to the grounded walls of the chamber was set by bias voltage source U_b. The variation of the beam plasma potential with gas pressure was monitored from the respective dependence of floating potential φ_p of the probe. Beam-generated plasma concentration n inside the chamber was estimated from the saturation current in the ion part of the I–V characteristic. Electron temperature T_e determined in the exponentially ascending electron branch of the probe characteristic fell into the range 0.5–2.0 eV. Collector *6* was placed on the bottom of the bulb. Its electrical lead could be either connected to or disconnected from the body of the chamber, thereby making it possible to measure electron beam current toward the collector or floating potential φ_c of the collector. To compare plasma generation conditions, the electron beam in a separate experiment was injected into the bulb under lower working pressures, 0.01–0.10 Pa. We also compared the plasma potential and plasma density inside the quartz bulb and in the free zone of the electron beam transport.

EXPERIMENTAL DATA

Figure 2 plots floating potential φ_c of the isolated collector versus voltage U_a across the accelerating gap of the electron source at different gas pressures. When the beam is injected into the quartz bulb in the forevacuum pressure range, floating potential φ_c of the isolated collector remains negative and declines with increasing accelerating voltage U_a. The absolute value of φ_c remains much smaller than U_a. The U_a dependence of φ_c has two portions corresponding to different current flow conditions after the injection of the electron beam into the quartz bulb. In the first portion, the plasma glow intensity inside the bulb is high and floating potential φ_c is maximal and remains almost unchanged with a rise in accelerating voltage U_a. In the second portion (at $U_a > 5$ kV), the glow intensity is much lower and potential φ_c decreases with increasing voltage U_a. It is noteworthy that, at the lower pressure (significantly lower than the fore-vacuum pressure range), the potential of the isolated collector almost reaches the accelerating voltage (curve *4*).

Experimental data suggest that a beam-plasma discharge (BPD) arises within the first portion of curves *1*–*3*, which was observed previously [8] when the beam freely propagated in the forevacuum pressure range. Even if the collector is enclosed in a dielectric cavity, the BPD plasma with a higher concentration provides unhindered charge drainage from the surface of the collector with its potential remaining unchanged. As the electron energy rises, the BPD conditions become disturbed and the density of the beam plasma drops, causing the potential of the collector to decline.

The differences in the transport conditions for the beam propagating in an unbounded space and injected into the bulb with dielectric walls are illustrated in Figs. 3 and 4 showing the pressure dependences of probe floating potential φ_p and plasma concentration n. When the beam freely propagates, φ_p is close to zero and slightly decreases with rising pressure. In the case of the beam injected into the bulb, potential φ_p is initially (at a minimal pressure) sharply negative but then markedly increases with gas pressure.

Since the behavior of φ_p correlates with the behavior of the beam plasma potential, the run of φ_p with rising pressure in the case of the free and bounded propagation of the beam may be related to different factors responsible for the retention and escape of plasma electrons. Unlike the potential, the plasma concentra-

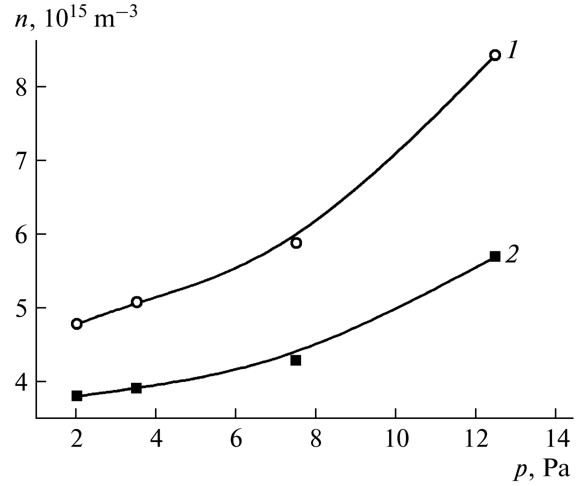

Fig. 4. Plasma concentration vs. the gas pressure for the electron beam (*1*) injected into the bulb and (*2*) propagating in an unbounded space The accelerating voltage is $U_a = 3$ kV, $I_b = 20$ mA.

tion grows with pressure in both cases and the plasma density inside the bulb is higher at all pressures (Fig. 4).

CONCLUSIONS

The feasibility of generating a beam plasma inside a dielectric container using a forevacuum plasma electron source is demonstrated. It is shown experimentally that the beam plasma potential inside the container is negative and grows with pressure. The beam plasma concentration in the container is higher than the plasma concentration in an unbounded space. Charges on the inner surface of the container can be neutralized more effectively by initiating a BPD. Experimental data indicate that an electron beam can be used to generate a plasma for ion–plasma modification of the inner surfaces of products made of insulating materials.

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