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GLOW DISCHARGE WITH AN EXTENDED HOLLOW CATHODE

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A low-voltage low-pressure glow discharge with a hollow cathode is discussed. The discharge is ignited in a reflective discharge system with two symmetric peripheral discharge chambers and a common extended hollow cathode at a forevacuum pressure. The plasma parameters and the admissible plasma column diameter in the hollow cathode are determined. It is shown that there is no electric double layer in the region of the output aperture of the cathode cavity.

Keywords: glow discharge, plasma, hollow cathode, symmetric discharge chambers, probe measurements.

INTRODUCTION

The discharge electrode scheme with a tubular cathode cavity is widely used in designing high-performance technological electron [1] and ion [2] guns. In the case of axial beams, the particles are selected from the plasma through the axial emission channel in the additional (emitting) cathode. However, a small diameter and an inhomogeneous radial distribution of the emitting plasma inhibit the generation of ribbon charged-particle beams in such electrode schemes. A traditional range of pressures, where the electron sources with plasma cathodes function, is within 10^{-3}–0.1 Pa [3]. However, in terms of generating the dense beam plasmas, the most optimal range of pressures is a few orders of magnitude higher, 1–100 Pa [4], corresponding to an average vacuum or forevacuum, which is formed using mechanical pumping systems only – forevacuum pumps. The electron sources, capable of generating electron beams at such pressures, began to be referred to as forevacuum sources [5]. The emitted plasma homogeneity can, in turn, be affected by the discharge parameters, cathode cavity geometry and gas pressure [6].

The purpose of this work is to study the extended plasma of a low-voltage low-pressure glow discharge with a common cylindrical hollow cathode and two symmetric discharge chambers.

EXPERIMENTLA SETUP

In the case of discharge initiation using two discharge chambers, located coaxially on both ends of a hollow cathode, we can obtain a homogenous plasma density distribution along the hollow cathode axis [7]. The discharge is initiated in a reflective discharge system (Fig. 1).

A magnetic field induction of 0.16 T in the cavity of copper anode cylinders *2*, *7* is provided by the constant ring magnets *3*, *6*. Plate cathodes *1*, *8* and a hollow cylindrical cathode *5* are manufactured from magnetic steel. The plate cathodes *1* and *8*, the anodes *2* and 7 and the cut ends of the hollow cathode *5* form two symmetrical discharge cells. The wall of the hollow cylindrical cathode *5* with a radius of 2 mm and a length of 66 mm has a longitudinal slit with a length of $L = 50$ mm and a width of 1 mm for the plasma diagnostics using a single mobile tungsten probe *4* with a diameter of 0.2 mm. The probe protruded up to the hollow cathode axis. The size of the protrusion was selected taking into account the value of the plasma stability ratio in the cavity [8] calculated as $r_{\min}/R \geq \xi$, where $r_{\min}$ is the plasma

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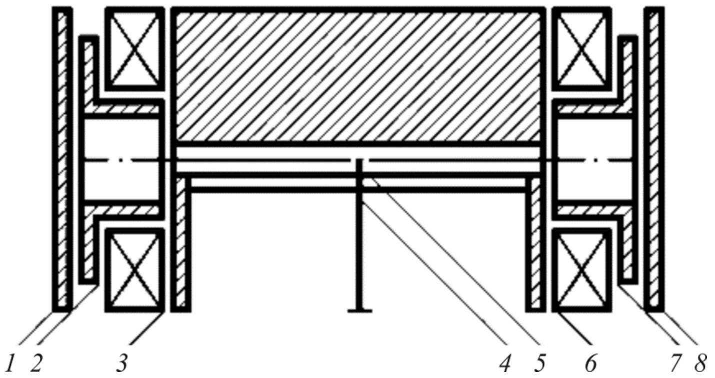

Fig. 1. Schematic of the gas discharge system: *1*, *8* – plate cathodes, *2*, *7* – cylindrical anodes, *3*, *6* – constant ring magnets, *4* – cylindrical probe, *5* – hollow cathode.

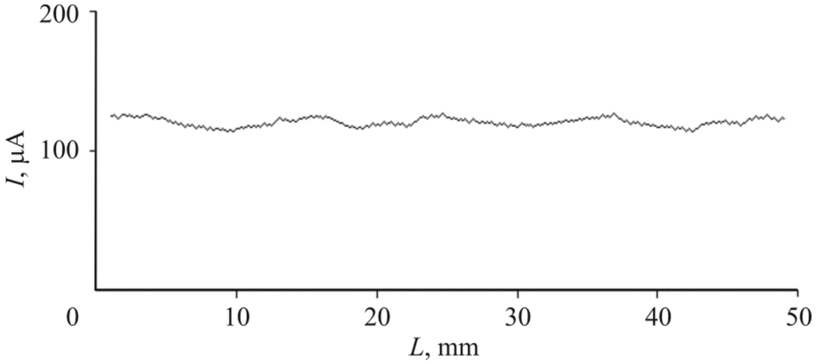

Fig. 2. Distribution of the probe ion current I_i along the slit length of the hollow cathode.

boundary radius, R is the cavity radius, $\xi \sim 0.3$. In other words, the minimum plasma radius in the cathode cavity can be 0.6 mm. At a residual air pressure of 10.9 Pa, the discharge voltage was 200 V and the discharge current was 50 mA per each discharge cell, with the plasma penetrating the hollow cathode simultaneously with the glow discharge ignition [9].

DETERMINATION OF PLASMA PARAMETERS

The ion current distribution in the probe during its motion along the hollow cathode axis is given in Fig. 2.

It has been found out in the experiment that in the case where the ion and electron currents of the probe are equal, the floating potential of the probe U_p is found to be 27 V, and the plasma space potential U_{pl}, equal to 50 V, is found from the electronic saturation current (Fig. 3).

The electron temperature T_e was found to be equal to $6 \cdot 10^4$ K, using the Langmuir probe procedure $T_e = (e/k)(\Delta U/\Delta \ln I)$, where e is the electron charge, k is the Boltzmann constant, ΔU is the potential difference delivered to the probe, and $\Delta \ln I$ is the logarithmic difference of the respective currents to the probe.

The densities of the chaotic electron and ion currents were determined at the plasma potential and were found to be 880 mA/cm^2 and 4.7 mA/cm^2. The electron concentration n_e was found to be $1.5 \cdot 10^{11}$ cm^{-3}, using the density of the electronic saturation current.

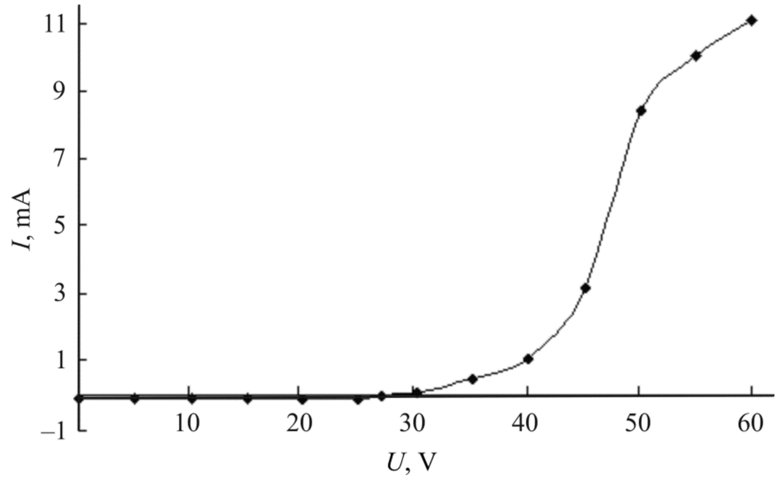

Fig. 3. Dependence of the probe current I on the voltage U delivered to the probe.

$$j_{\mathrm{es}} = n_e e (kT_e / 2\pi m)^{1/2} \exp(-e(U_{\mathrm{pl}} - U_{\mathrm{pr}}) / kT_e), \tag{1}$$

at $U_{\mathrm{pr}} = U_{\mathrm{pl}}$, where U_{pr} is the probe potential and m is the electron mass. The ion concentration n_i was found to be equal to $1.5 \cdot 10^{11}$ cm^{-3}, using the Bohm formula for the density of the ionic saturation current

$$j_{\mathrm{is}} = 0.57 n_i e (kT_e / M)^{1/2}, \tag{2}$$

where M is the averaged mass of an air ion ($3.9 \cdot 10^{-26}$ kg). The floating potential was calculated by equating the electronic (1) and ionic (2) current densities at $U_{\mathrm{pr}} = U_p$

$$U_p = U_{\mathrm{pl}} - (kT / e) \ln(0.7 (M / m)^{1/2}).$$

The calculations yielded the floating potential value of 26.6 V, which is also consistent with the experimental value. The length of the cathode voltage drop region d_c can be determined from a combined solution of the Child–Langmuir $j_i = (4/9)(2e/M)^{1/2} \varepsilon_0 U_{\mathrm{pl}}^{3/2} / d_c^2$ (here ε_0 is the electric constant) and Bohm (2) equations for the plasma ion current

$$d_c = 1.05 (\varepsilon_0 / n_i)^{1/2} U_{\mathrm{pl}}^{3/4} / (ekT_e)^{1/4},$$

with the calculations yielding $d_c = 0.2$ mm. In other words, the maximum plasma column radius $r_{\max}$ can be as large as 1.8 mm. Thus, in an extended hollow cylindrical cathode with a diameter of 4 mm, the admissible plasma column diameter is limited by the sizes from 1.2 to 3.6 mm. Figure 4 presents a photograph of a homogeneous distribution of the plasma visible through the longitudinal slit along the axis of the hollow cylindrical cathode.

There is no electrical double layer in the region of the output aperture of the cathode cavity, since the condition of its formation is not fulfilled [10]: $s_a/s_c < (m/M)^{1/2}$, where s_a is the area of the hollow cathode output aperture and s_c is the cathode surface area. The calculations demonstrate that $s_a/s_c = 1.57 \cdot 10^{-2}$ is larger than $(m/M)^{1/2} = 4.83 \cdot 10^{-3}$.

Fig. 4. Photo of the plasma visible through a slit along the hollow cathode axis.

CONCLUSIONS

In the present work we have determined the plasma parameters for a glow discharge with an extended hollow cathode and two symmetrical discharge chambers at a forevacuum pressure. It has been shown that in the extended cylindrical cathode 4 mm in diameter the admissible plasma column diameter is limited by the sizes from 1.2 to 3.6 mm and there is no double electrical layer in the region of the output aperture of the cathode cavity. The experimental gas discharge system proposed in this study can be used to generate homogeneous extended plasma in the sources of ribbon charged-particle beams.

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