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PLASMA DYNAMICS

Control for the Parameters of a Low-Pressure Glow Discharge in Argon by Means of Acoustic Flows

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Abstract—The possibility to control the parameters of a low-pressure glow discharge in argon by means acoustic flows is demonstrated by numerical simulations. It is shown that such flows result in an increase in the densities of charged and excited particles in the axial region of the discharge and contraction of the positive column, while stability of the discharge is preserved.

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1. INTRODUCTION

Gas-discharge plasma has received wide application in various branches of science and technology. In particular, it is used in high-power light sources [1], semiconductor industry (chipping) [2], bioengineering [3], surface modification, and deposition of coatings [4], as well as the active medium in space electric propulsion engines [5, 6].

In this context, slide control for the parameters of gas-discharge plasma at fixed values of the current and gas pressure is a challenging problem of present-day plasma physics and gas-discharge technology. Of special interest is the possibility to control the discharge structure [7–10], as well as the fluxes and densities of charged and excited particles.

It was shown in [7, 8] that plasma parameters could be varied in wide ranges by exciting acoustic oscillations in the gas-discharge tube. The plasma parameters are most strongly affected by resonance oscillations, at which the role of acoustic flows significantly increases due to nonlinearity. In [9], the effect of acoustic flows on the constricted glow discharge in argon with a strong radial gradient of the temperature was studied experimentally. The possibility to control the operating regime of a glow discharge with an extended positive column at a high gas pressure by organizing acoustic flows was demonstrated. In this case, the constricted regime of the discharge is changed to the diffuse one and the discharge becomes stable. However, as was shown in [11–13], application of an acoustic field to a low-pressure glow discharge can lead to the constriction of the positive column.

In this work, the effect of acoustic flows on a diffuse low-pressure glow discharge is studied by numerical simulations. The possibility to control plasma parameters at fixed values of the gas pressure and discharge current is shown.

2. MODEL

The velocity of acoustic flows excited in the field of a standing acoustic wave can be found from equations of motion for a viscous gas [14]. Let us consider a long narrow discharge tube, $R/L \ll 1$, with a standing acoustic wave (Kundt's tube). Let the annular cathode and anode be located in the velocity antinodes of the acoustic wave. The distance between the electrodes is chosen to be equal to one-half of the acoustic wavelength, $\lambda_a/2$. To simplify the problem on the effect of acoustic flows on the gas-discharge plasma, gas heating is disregarded, which is quite acceptable for low-pressure low-current discharges [15, 16]. In this case, from the set of Navier–Stokes equations, we obtain the following analytical expressions for the velocity field of acoustic flows [14]:

$$u_z = -\frac{3}{8}\frac{v_0^2}{c_0}\sin 2\kappa z\left[1 - 2\left(\frac{r}{R}\right)^2\right],$$
$$u_r = \frac{3}{8}\frac{v_0^2}{c_0}\kappa r\cos 2\kappa z\left[1 - \left(\frac{r}{R}\right)^2\right], \qquad (1)$$

where $v_0 = \delta P/(\rho c_0)$ is the velocity amplitude of acoustic oscillations, δP is the pressure amplitude of acoustic oscillations, ρ is the gas density in the tube, c_0 is the speed of sound, κ is the wavenumber, and R is the tube radius [14].