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Gas Discharge Sustained by Potential Surface Waves in Magnetized Waveguide Structure Filled by Radially Non–Uniform Plasma

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The report presents the results of theoretical investigation of axial structure of gas discharge that is sustained by the travelling slightly–attenuating potential surface wave (SW) in diffusion gas–discharge regime. Plasma density axial distribution along the discharge was studied in the framework of electrodynamic approach [1,2] and the main attention was devoted to the phase properties of the SW that sustains the discharge.

The SW considered propagates along radially non–uniform plasma column with radius R_p that is bounded by the glass tube with permittivity ε_d and outer radius R_g. This tube is surrounded by the vacuum region and is enclosed by the waveguide metal wall with radius R_m. External steady magnetic field $\vec{B}_0$ is directed along the axis of the waveguide system. Plasma is considered in hydrodynamic approximation as cold and slightly absorbing medium with the effective collisional frequency of momentum transfer ν, that much less than generator frequency ω and is constant in the whole discharge volume. Radial profile of electron density $n(r)$ was chosen in the Bessel–like form, given by $n(r)=n(0)J_0\left(\mu r R_p^{-1}\right)$, where $n(0)$ is plasma density value on the axis of the discharge structure, J_o – Bessel function of the zero order, μ is non–unifomity parameter. Such choice of a radial density profile allows one to model different discharge regimes with the help of changing nonuniformity parameter μ.

The propagation of the nonsymetric potential SW along the discharge structure is governed by the Poisson equation. Let us consider the case when plasma density, SW amplitude and wavelength vary slightly along the discharge column at the distances of wavelength order. Then the solution of the Poisson equation for the wave potential Ψ in the cylindrical coordinate system (r,φ,z) can be found in WKB form [3] and the equation itself can be written in the following local form:

$$\varepsilon_1 \frac{d^2\Psi}{dr^2}+\left\{\frac{\varepsilon_1}{r}+\frac{d\varepsilon_1}{dr}\right\}\frac{d\Psi}{dr}-\left(k_3^2\varepsilon_3+\frac{m}{r}\frac{d\varepsilon_2}{dr}+\frac{m^2}{r^2}\varepsilon_1\right)\Psi = 0, \qquad (1)$$

here $\varepsilon_{1,2,3}(r)$ – are components of permittivity tensor of the cold magnetized plasma [4].

In the regions of the glass tube and vacuum slab the Poisson equation possesses the solutions that can be obtained analytically and consists of the superposition of the modified Bessel functions. Applying linear boundary conditions [4] one can obtain the local dispersion equation and SW field constants in each media. Despite of the low value of the effective electron collisional frequency it is necessary to keep imaginary items in the components of the permittivity tensor ε_i to carry out the numerical integration of the equation (1) in the regions, where the conditions of the upper hybrid resonance take place.

The study of the local dispersion equation for the symmetric ($m = 0$) and dipolar wave ($m = -1$) were carry out by the numerical methods under different values of external discharge parameters. The choice of the symmetric and dipolar waves is stipulated by its wide practical use for gas discharge sustaining [1]. It is necessary to point that the solutions of the local dispersion equation are valid when the conditions of the potential wave existence are fulfilled. These limitations are essential for the SW with rather large azimuth wavenumbers. The increase of the SW azimuth wavenumbers m leads to the essential growth of the SW spatial attenuation coefficient, so these waves can effectively sustain only rather short discharges.

The results of this study are represented in the Fig. 1–4. The calculations were carried out for the typical discharge parameters: $\omega_{ce}\omega^{-1} = 0.72$, $R_m R_p^{-1} = 2.5$, $R_g R_p^{-1} = 1.05$, $\varepsilon_d = 5.0$ and $\nu\omega^{-1} = 0.06$. Numbers on the curves 1, 2, 3, 4, 5, 6 corresponds to the case of $\mu = 0.5, 1.0, 1.5, 2.0, 2.2, 2.4$, respectively. The calculations have shown that phase characteristics (the dependence of $N = \omega_{pe}^2\omega^{-2}$ on the $\mathrm{Re}(k_3)R_p$, ω_{pe} is electron plasma frequency) and SW spatial attenuation coefficient ($\alpha = \mathrm{Im}(k_3)R_p$) are determined by the non–uniformity parameter μ in a great extent. The increase of the non–uniformity parameter leads to the increase of N under the fixed $\mathrm{Re}(k_3 R_p)$ value (Fig. 1, 3). But the strongest influence of the non–uniformity parameter is observed on the wave spatial attenuation coefficient (Fig. 2, 4). In the case when the conditions of the upper hybrid resonance take place at the periphery of the plasma column the SW attenuation coefficient becomes rather great (curve 6). It is necessary to note that the dependence of α via N for symmetric and dipolar wave essentially differs (Fig. 2, 4). This is important for the problem of the stability of the discharge [1].

Let consider wave field structure. The dependence of the radial SW field structure on the parameter μ is similar for the symmetric and dipolar modes. The SW radial field structure for the dipolar SW in the case when $\mu = 1.8$ is presented in the Fig. 5.

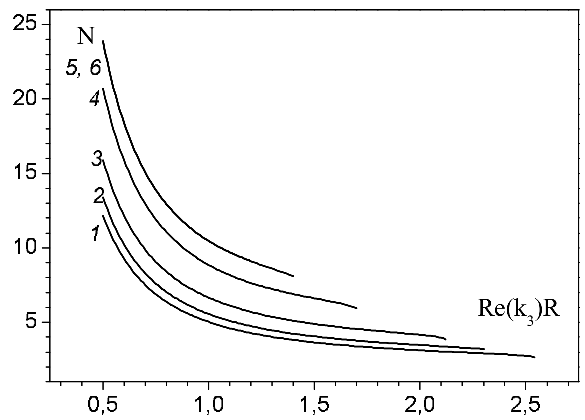

Fig.1. Phase characteristics of the symmetric surface wave $(m = 0)$.

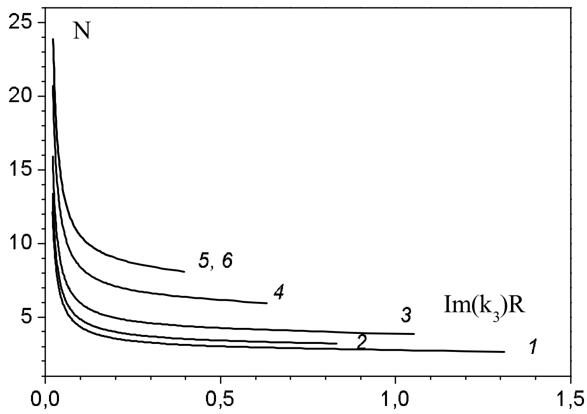

Fig.2. Spatial attenuation coefficient of the symmetric wave $(m = 0)$.

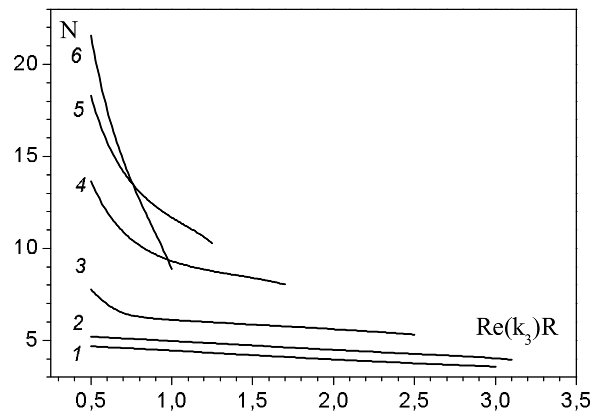

Fig.3. Phase characteristics of the dipolar surface wave $(m = -1)$.

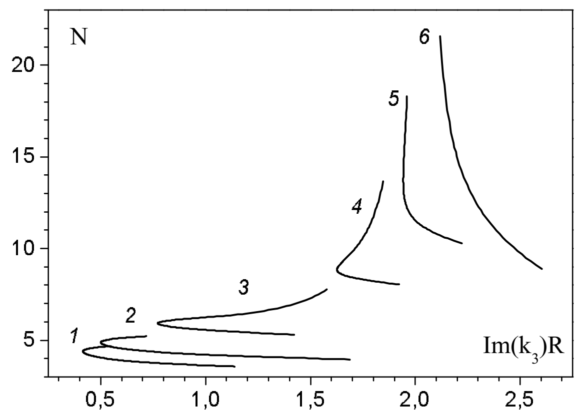

Fig.4. Spatial attenuation coefficient of the dipolar wave $(m = -1)$.

The growth of the non–uniformity parameter leads to the essential change of the SW radial field structure and therefore the SW energy input in the discharge. When parameter μ leads to the value that is typical for the discharges in ambipolar regime of charged particles

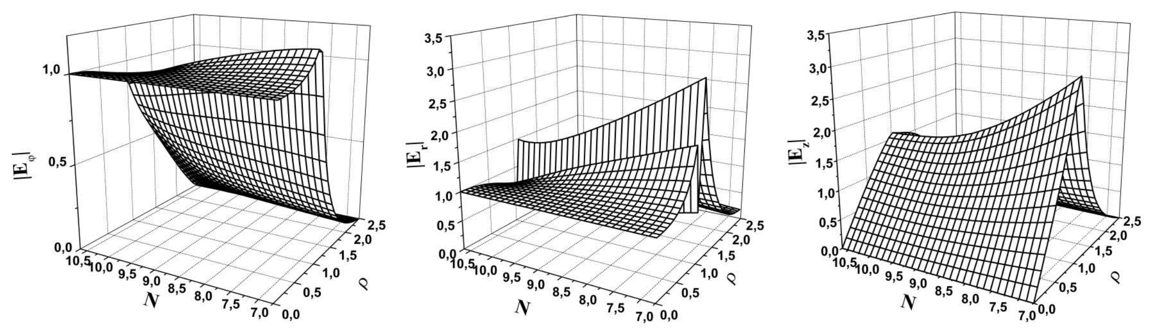

Fig.5. SW field structure for dipolar wave when $\mu = 1.8$.

losses the radial SW field component sharply growth at the periphery of the plasma region and the total wave field structure tends to the structure of the volume wave.

The carried out investigation gives the possibility to determine the axial plasma density profile. It is necessary to use the power balance relation, assuming that the dependence of $\alpha(n)$ is known [1,2]. For the discharges in the diffusion controlled regime this relation leads to:

$$\frac{dn(z)}{dz} = -2\alpha(n)n(z)\left(1 - \frac{n(z)}{\alpha(n)}\frac{d\alpha(n)}{dn}\right)^{-1}. \tag{2}$$

This equation gives the axial distribution $n(z)$ of the average electron density over a cross section of discharge structure at known dependence $\alpha(n)$. The results of numerical investigation of the plasma density axial structure in the discharge sustained by symmetric SW are represented in Fig. 6. Numbers on the curves 1, 2, 3 corresponds to the case of $\mu = 0, 2.2, 2.4$, respectively. The increase of nonuniformity parameter μ leads to the growth of the maximum value of the plasma density and to the decrease of the discharge length. So, plasma density axial gradients increase while plasma density radial profile comes closer to the perfect ambipolar diffusion profile.

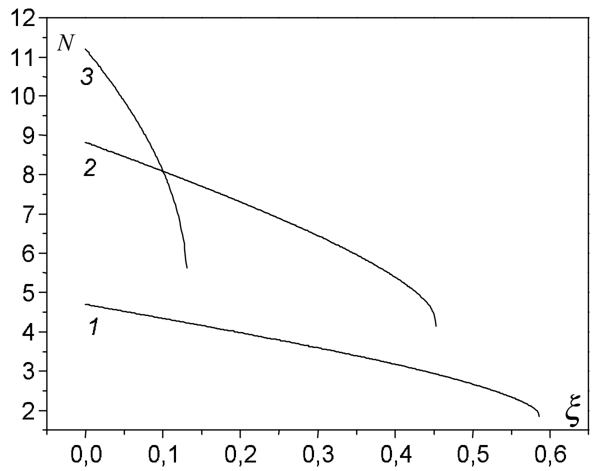

Fig.6. Dimensionless plasma density axial profile ($\xi = \nu z(\omega R_p)^{-1}$) in the discharge sustained by the symmetric mode.

Acknowledgment

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References

[1.] Moisan M., Zakrzewski Z., *Journal of Physics D: Applied Physics*, **24** 1025 (1991).

[2.] R. Darchicourt, S. Pasquiers, C. Boise–Laporte, P. Leprince, J. Marec *Journal of Physics D: Applied Physics*, **21** 293 (1988).

[3.] Lister GG., Robinson T.R., *Journal of Physics D: Applied Physics*, **24** 1993 (1991).

[4.] Kondratenko A.N., *Surface and Volume Waves in Bounded Plasma.* Energoatomizdat, Moscow, 1985.