Topic number: 5

RADIAL THEORY OF IONIC CURRENT TO A PROBE IN LOW PRESSURE PLASMA WITH ALLOWANCE FOR VOLUME IONIZATION AND COLLISIONS WITH NEUTRALS

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At present radial [1] and orbital [2, 3] theories are being applied to interpret the ionic part of probe characteristic. The latter is valid when ions have a considerable angular momentum (the ion temperature is nonzero) and the collisionless approximation is suitable. It is important to note that even rare collisions of ions with neutrals disrupt the orbital motion of particles and affect strongly the ionic current value [4, 5]. When the orbital model fails the radial drift theory is more applicable. The effect of collisions with neutrals (resonant charge exchange) in radial drift approach at low and intermediate pressures was considered in [6]. If one does not take into account volume ionization the disturbed region has to be increased to infinity. Finite size of the disturbed region affects the ionic current. Besides, it defines spatial resolution of the method.

The work presents the results of calculations of ionic current to spherical and cylindrical probe with allowance for ionization and collisions with neutrals in the approximation of cold ions. Current-voltage characteristic of probes have been calculated for dimensionless parameters $r_з / \lambda_д = 0.0001 \div 10$, $\lambda_i / \lambda_д = 0.01 \div 10$. All the ions collected by probe are produced with volume ionization frequency $n_e z$ inside the disturbed region r_0. Ions produced outside of r_0 move to walls and electrodes. Taking into consideration ionization and ion-neutral collisions total ionic concentration in r is given by the equation:

$$n(r) = \frac{1}{r^\alpha} \int_r^{r_0} \frac{r'^\alpha [n_e(r')z + \frac{j'}{e\lambda_i}] \exp\left[-\frac{(r'-r)}{\lambda_i}\right] dr'}{\sqrt{\frac{2e}{M}[\varphi(r') - \varphi(r)]}}, \text{ where } j' = \frac{e}{r'^\alpha} \int_{r'}^{r_0} n_e(r'')zr''^\alpha \, dr'',$$

where $\alpha = 2$ and $\alpha = 1$ for spherical and cylindrical geometry correspondingly. The $n_i(r)$ dependence coincides with the Langmuir's "plasma-sheath" equation [7] in the collisionless case, but the boundary conditions are inverse (internal collector). The expression for $n_i(r)$ was substituted into the Poisson's equation, the latter was solved at the boundary conditions $\varphi(r_0) = 0$, $\frac{d\varphi}{dr}|_{r_0} = 0$. To use the results independently of plasma parameters the calculations were carried out for dimensionless parameters: $x = \frac{r}{\lambda_d} = \frac{re}{\sqrt{\varepsilon_0 kT_e / n_0}}$; $U = \frac{e\varphi}{kT_e}$; $n' = \frac{n}{n_0}$; $l_i = \frac{\lambda_i}{\lambda_д}$; $A = \frac{Z\lambda_d}{\sqrt{kT_e / M}} = \frac{Z}{\omega_i}$; $j' = n'V' = \frac{j}{en_0\sqrt{kT_e / M}}$, where ω_i - ionic plasma frequency, $\lambda_д$ - electronic Debye radius. In the figure 1 current-voltage characteristics of very small spherical probe ($a = \frac{r_p}{\lambda_d} = 0.001$) are presented, collisions are ignored ($l_i = \frac{\lambda_i}{\lambda_\partial} = \infty$). The result of the pure radial theory [8,9,10] is shown for comparison.

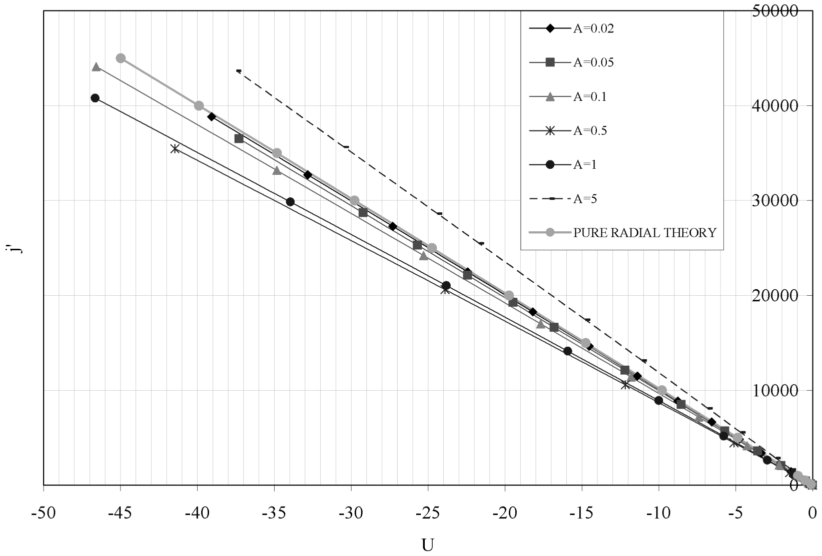

Fig.1: Comparison of the radial theory [1] with the results of the presented work,

$$a = \frac{r_p}{\lambda_d} = 0.001$$

Let us analyze the results of the collisionless case. At small r_0 (case of large ionization frequncy) ions born by ionization move rapidly to the probe, they produce large current. The ionic current drops with the increase of the disturbed region and, therefore, ions path. At larger distances the ionic current increases slightly again, because drift velocity of the ion produced begins to increase. The results converge to those of the theory of radial drift in case of $z \to 0$ (hence $r_0 \to \infty$) when the collisions are neglible (see Fig.1). In the collisional case the ionic current depends on ionization frequency and free path of ions. The ionic current as well as the disturbed region decreases monotonously with the free path at constant ionization frequency.

Reference

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