FIELD EMISSION WITH ALLOWANCE FOR THE EFFECT OF INDIVIDUAL ION FIELDS (I-F EMISSION)

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An analytical expression is obtained for calculating the current density of I-F emission. It is shown that the magnitude of the current depends on the parameters of the cathode (the work function φ), of the plasma (the field strength E_0 at the cathode and the ion concentration n), and on a value characterizing the joint properties of the cathode and plasma (the neutralization distance l_*).

The idea of taking into account the effect of the individual fields of ions moving in the layer near the cathode on the current density of the field emission (F emission) was expressed in [1]. There also calculations were made for the concrete values of the plasma and cathode parameters, but analytical dependences could not be obtained because of mathematical difficulties.

In [2] an attempt was made to obtain an analytical dependence for the calculation of the field emission current density with allowance for the fluctuating electric field (I-F emission). The results of [2], agreeing with the results of [1] in the concrete values of the work function φ and the neutralization distance l_* of the ions, show that the current density of I-F emission can considerably exceed the current density of F emission.

The results obtained in [2] are valid only for high ion concentrations in the cathode layer, but the current density j_{I-F} of I-F emission can be considerably greater than the field emission current density j_F even at $n \sim 10^{17}$-10^{19} cm^{-3}, where n is the ion concentration.

Allowing for the discrete charge of the ions, the electric field strength E at the cathode can be considered as a random value, taking on values from min $E = E_0$ up to max $E = E_*$, and then the emission current density j_{I-F} can be determined as follows:

$$j_{I-F} = \int_{E_0}^{E_*} j_F(E) \quad f(E, E_0)\, dE \tag{1}$$

where $f(E, E_0)$ is the distribution function of the electric field strength at the cathode in the presence of an external field E_0.

In [3, 4] a distribution function was obtained for the electric field strength ε at the cathode produced by the motion of ions in the region near the cathode

$$f(\varepsilon) = \frac{2\pi n}{5} \frac{(600q)^{3/2}}{\varepsilon^{5/2}} \exp\left[-\frac{4\pi n}{15}\left(\frac{(600q)}{\varepsilon}\right)^{3/2}\right] \tag{2}$$

Here the ion concentration n at the surface of the cathode is expressed in cm^{-3} while the field ε is in V/cm. The distribution (2) is obtained from an examination of the "nearest neighbor" model [4], when the effect of the ensemble of ions is neglected. Such an approach is admissible only for large fields, although in this region the nearest neighbor distribution function approaches the distribution function for an ensemble of particles. But a large field is of interest for field emission.

In the presence of a superimposed field E_0 the distribution function of the resultant field $E = E_0 + \varepsilon$ takes the form

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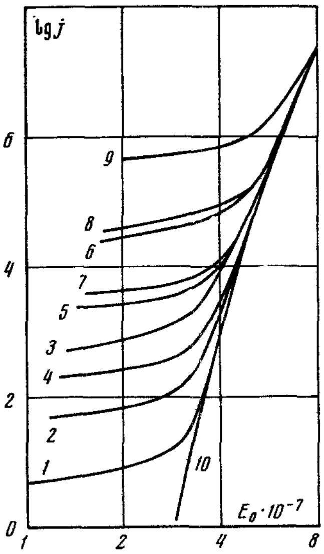

Fig. 1

$$f(E, E_0) = \frac{2\pi n}{5} \frac{(600q)^{3/2}}{(E - E_0)^{5/2}} \exp\left[-\frac{4\pi n}{15}\left(\frac{600q}{E - E_0}\right)^{3/2}\right] \tag{3}$$

For the calculation of $j_F(E)$ the equation [5]

$$j_F(E) = \frac{1.55 \cdot 10^{-6} E^2}{\varphi} \exp\left[-\frac{6.85 \cdot 10^7 \varphi^{3/2}}{E} \theta(E)\right] \tag{4}$$

is used, where θ (E) is the Nordheim function. Usually θ (E) is given in the form of tables or graphs. An analysis of these data shows that the dependence θ (E) for $E \in [10^7 - 10^8]$ V/cm can be approximated by the linear function

$$\theta(E) = \alpha - \beta E \tag{5}$$

Making use of Eqs. (3)-(5) we obtain from (1)

$$j_{I-F} = A_n \frac{155 \cdot 10^{-6}}{\varphi} \frac{2\pi n}{5} (600q)^{3/2} \exp(6.85 \cdot 10^7 \varphi^{3/2} \beta) \int_{E_0}^{E_*} \frac{E^2}{(E - E_0)^{5/2}} \exp\left[-\frac{6.85 \cdot 10^7 \varphi^{3/2} \alpha}{E} - \frac{4\pi n}{15}\left(\frac{600q}{E - E_0}\right)^{3/2}\right] dE \tag{6}$$

where A_n is the normalization coefficient of the distribution function (3)

$$A_n = \left[\int_{E_0}^{E_*} f(E, E_0) dE\right]^{-1} = \exp\left[\frac{4\pi n}{15}\left(\frac{600q}{E_* - E_0}\right)^{3/2}\right]$$

An approximate calculation of the integral of (6) (the calculation error in all cases does not exceed 10%) leads to the result

$$j_{I-F} = \frac{1.55 \cdot 10^{-6}}{\varphi} E^2 \exp\left[-\frac{6.85 \cdot 10^7 \varphi^{3/2}}{E_0} \theta(E_0)\right] \times \left\{1 + \frac{2.84 \cdot 10^{-18} n E_*^4}{E_0^2 (E_* - E_0)^{5/2} \varphi^{3/2}} \exp\left[6.85 \cdot 10^7 \varphi^{3/2} \left(\frac{\theta(E_0)}{E_0} - \frac{\theta(E_*)}{E_*}\right)\right]\right\} \tag{7}$$

The dependence (7) for $\varphi = 4.5$ V is presented graphically in Fig. 1 for different values of n and E_* (curves 1, 2, and 3 correspond to $E_* = 6 \cdot 10^7$ V/cm; 4, 5, 6) $E_* = 9 \cdot 10^7$; 7, 8, 9) $E_* = 12 \cdot 10^7$; 1, 4, 7) $n = 10^{17}$ cm^{-3}; 2, 5, 8) $n = 10^{18}$; 3, 6, 9) $n = 10^{19}$; 10) n = 0, i.e., F emission).

As seen from the graphs, the current density of I-F emission can considerably exceed the current density of F emission for the same values of the field E_0. In contrast to [1, 2], where the field E_0 was taken as the first moment of the distribution function of the probability density of the electric field strength at the cathode, the field E_0 which enters into (7) is the field which can be created at the cathode and is not formally connected with the ion concentration n in the cathode layer.

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