THERMOAUTOELECTRONIC EMISSION TAKING ACCOUNT OF INDIVIDUAL IONIC FIELDS

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In [1] analytical expressions were obtained for calculation of the current density of a thermoautoelectronic emission in a vacuum. In the region of high temperatures and weak electric fields, the corresponding formula has the form

$$j = AT^2 \exp\left[-\frac{\chi'}{kT}\right]\left\{\sum_{n=0}^{\infty}(-1)^n \frac{(2n+1)\mu}{n(n+1)\mu^2+\mu-1} - \frac{W_a^{1/2}}{2kT}\left(1-\frac{W_a^2}{4x_0^2}\right) \times \right.$$
$$\left. \times\left[\frac{\cos v_{01}}{\{[\pi\alpha+1/kT]^2+\beta^2\alpha^2\}^{1/2}} + \frac{\cos v_b}{\{[2\pi\alpha-1/kT]^2+\beta^2\alpha^2\}^{1/2}}\right]\right\},$$

where $a = 0.527$ Å is the atomic unit of length; $e^2/2a = 13.67$ eV is the energy unit; $\alpha = (^1/_2x_0^3)^{1/2}$; $\mu = 2\pi\alpha kT$; $x_0 = (\sqrt{300e}/F)(10^8/2a)$ is the Schottky distance; F is the intensity of the electric field, W/cm; χ is the work function; $\chi' = \chi - 1/x_0$ is the work function taking account of the Schottky effect; γ is the Euler constant (γ = 0.5772); $\beta = \gamma + \ln 2$;

$$v_a = \frac{4\sqrt{2}}{3}x_0^{1/2} - \frac{2}{W_a^{1/2}} + \mathrm{tg}^{-1}\frac{W_a^{1/2}}{4} - \mathrm{tg}^{-1}\frac{\beta\alpha}{\pi\alpha+1/kT};$$

$$v_b = \frac{4\sqrt{2}}{3}x_0^{1/2} - \frac{2}{W_a^{1/2}} + \mathrm{tg}^{-1}\frac{W_a^{1/2}}{4} + \mathrm{tg}^{-1}\frac{\beta\alpha}{\pi\alpha-1/kT}.$$

If we neglect the relatively small periodically varying term, then

$$j = AT^2 \exp[-\chi'/kT]\sum_{n=0}^{\infty}(-1)^n \frac{(2n+1)\mu}{n(n+1)\mu^2+\mu-1}. \qquad (1)$$

Expression (1) is generally used for calculating the current density of a thermoautoelectronic emission in the plasma of an arc discharge [2]; here the intensity of the electric field is obtained from the McGowan equation

$$F = \sqrt{7.57\cdot 10^5 (V_c)^{1/2}\{j_i 1845 M^{1/2} - j_e\}}, \qquad (2)$$

where j_i and j_e are the densities of the ionic and electronic current at the cathode; V_c is the precathode potential drop; and M is the atomic weight of an ion.

Equation (2) offers the possibility of determining only the mean value of the intensity of the electric field at the cathode, without taking account of its fluctuations, which arise due to the motion of individual ions in the layer of the space charge ahead of the cathode. Taking account of such fluctuations, carried out in [3, 4] for thermoelectronic and in [5] for autoelectronic emissions, pointed to the possibility of a considerable increase in the current density of T- and F-emissions. We shall carry out a calculation to determine the current density of a thermoautoelectronic emission taking account of individual ionic fields (I–F–T- and I–T–F-emissions).

In [6], the distribution function of the probability density of the corrections to the work function, arising with the approach of an ion to the surface of the cathode, $f(\Delta\chi)$, was obtained. (In the case where account is taken of the discrete character of the distribution of the charge in the precathode layer, $\Delta\chi \neq \sqrt{eE} = \Delta\chi_{Sch}$, where $\Delta\chi_{Sch}$ is the Schottky correction.) Then to obtain the mean value of the current density of an I–T–F-emission, the current density of a T–F-emission must be averaged with respect to the distribution function $f(\Delta\chi)$, i.e.,

Moscow. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 2, pp. 25–28, March–April, 1978. Original article submitted January 18, 1977.

 0021-8944/78/1902-0164$07.50

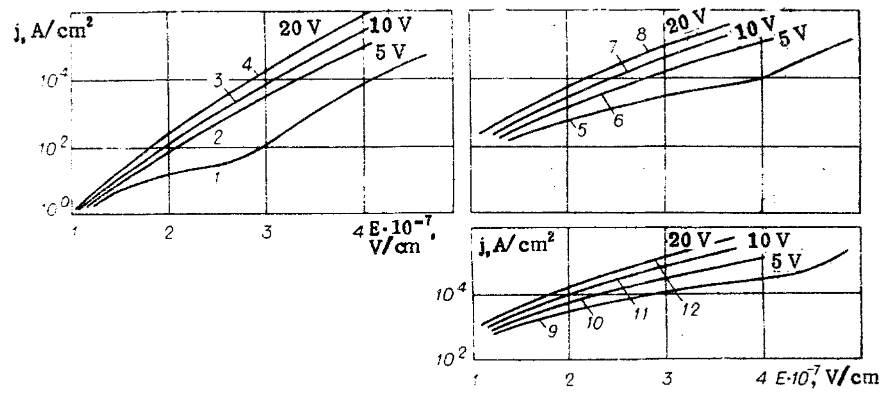

Fig. 1

$$\langle j_{I-T-F}\rangle = \int\limits_{\Delta\chi_{\min}}^{\Delta\chi_{\max}} j_{T-F}(\Delta\chi) f(\Delta\chi) d(\Delta\chi). \tag{3}$$

Figure 1 gives the results of calculations using formula (3) for materials with a work function $\chi = 4.5$ V (tungsten, mercury) and temperatures of 2000, 2500, and 3000°K [curves 1, 5, and 9 were calculated using formula (2); curves 1-4 relate to a temperature of 2000°K, 5-8 to 2500°K, and 9-12 to 3000°K; the numbers on the curves denote the cathode potential drop].

The mean value of the intensity of the electric field at the surface of the cathode was calculated taking account of the contribution of the mean field from the nearest ion:

$$F = 4\pi nde[1 - 0.38\ R^{-1/3}],$$

where R is a dimensionless parameter, whose values are given in Table 1 for different values of the pre-cathode potential drop and of the intensity of the electric field at the cathode.

From Fig. 1 it can be seen that the current density of an I−T−F-emission can exceed the current density of a T−F-emission by more than an order of magnitude and that this effect increases with a rise in the dimensionless parameter $H = e\sqrt{eF}/kT$.

We note that, for temperatures of the cathode below 2500°K, with an intensity of the electric field $F > 4\cdot 10^7$ V/cm, a significant role starts to be played by an I−F−T-emission, which takes account of electrons, overcoming the potential barrier as a result of the tunnel effect, and not over the barrier, as for I−T−F- and T−F-emissions.

In this case, the expression for the current density of an F−T-emission has the form [1]

$$j_{F-T} = \left\{1.55\cdot 10^{-6}\frac{F^2}{\theta^2\chi} + 120T^2\sum_{n=1}^{\infty}\frac{(-1)^{n+1}}{n}\,\frac{1}{n + 8.81\cdot 10^{3}\theta\chi^{1/2}T/F}\right\}\exp[-6.84\cdot 10^{7}\theta\chi^{3/2}/F],$$

where θ is a Nordheim function, whose values are given in [1].

To calculate the current density of an I−F−T-emission, j_{F-T} must be averaged over the distribution function of the probability density of the transparency of the potential barrier f(Q):

$$\langle j_{I-F-T}\rangle = \int\limits_{Q_{\min}}^{Q_{\max}} j_{F-T}(Q) f(Q)\, dQ. \tag{4}$$

The function f(Q), obtained in [5], has the form

$$f(Q) = 2.5\cdot 10^{-21} n\left[\frac{Q_{\max}}{(Q_{\max}-Q)^2} - \frac{1}{Q_{\max}}\right]\exp\left[-2.5\cdot 10^{-21} n\left(\frac{Q_{\max}}{Q_{\max}-Q} - \frac{Q}{Q_{\max}} - 1\right)\right],$$

where $Q_{\max} = {}^2/_3(\chi^{3/2}/F)\theta(F)$.

Averaging (4), we can determine the current density of an I−F−T-emission, shown in the right-hand part of Fig. 1. It can be seen that the current density of an I−F−T-emission can considerably exceed the current density of an F−T-emission.

TABLE 1

V_c, volts	5				10				20			
E, V/cm	$4\cdot10^6$	$8\cdot10^6$	$1{,}6\times10^7$	$3{,}2\times10^7$	$4\cdot10^6$	$8\cdot10^6$	$1{,}6\times10^7$	$3{,}2\times10^7$	$4\cdot10^6$	$8\cdot10^6$	$1{,}6\times10^7$	$3{,}2\times10^7$
R	6,2	3,1	1,55	0,77	25	12,5	6,2	3,1	100	50	25	12,5

In conclusion, we note that, for temperatures above 2500°K and fields $F < 5\cdot10^7$ V/cm, the fraction of electrons overcoming the potential barrier as a result of the tunnel effect is considerably less than the fraction of electrons passing over the barrier j_{I-F-T}. For temperatures below 2500°K and fields of $(3\text{-}5)\cdot10^7$ V/cm, the current density can attain j_{I-F-T} and then, with a rise in the field, can considerably exceed j_{I-T-F}.

With a transition from an I−T−F- to an I−F−T-emission, the point of inflection on the curves is almost not visible, while, with a transition from a T−F- to an F−T-emission, there is a sharp point of inflection with fields of $\sim4\cdot10^7$ V/cm, where the tunnel effect begins to be strongly felt. The effect of the discrete character of the distribution of the charge in the precathode layer rises with a rise in the precathode potential for I−T−F- and I−F−T-emissions, which is connected with a rise in the dimensionless parameter $R = nd^3$.

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CHARACTERISTICS OF A TWO-STAGE ION ACCELERATOR WITH AN ANODE LAYER

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UDC 629.7.036.74

Introduction

Plasma accelerators with a closed Hall current [1] are now undergoing ever greater development. From the macroscopic point of view the acceleration of plasma in these devices is accomplished by the electromagnetic force produced by the interaction of the Hall current with the external magnetic field. The concrete mechanism of the manifestation of this force consists in the fact that if the electrons are magnetized, then an electric field can be created in the plasma which accelerates the ions, whereas the electrons are forced to drift in the direction of the vector $[\mathbf{E}\times\mathbf{H}]$. If the conditions are uniform in the direction of the drift, then the drift or Hall current which develops closes on itself and the necessity of its commutation drops out.

Great attention is paid to one modification of an accelerator with closed drift: an accelerator with an extended acceleration zone and with dielectric walls for the accelerator chamber [2-6]. This system has been studied since the start of the 1960s. Serious development of another modification − an accelerator with an anode layer, most easily formed above metal cathode walls − began somewhat later, although the principle of

Kaliningrad, Moscow, Oblast. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 2, pp. 28-36, March-April, 1978. Original article submitted December 29, 1976.

0021-8944/78/1902-0166$07.50