INFLUENCE OF MICROSCOPIC AEROSOL PARTICLES ON EMISSION CHARACTERISTICS OF COLD CATHODE

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Processes which take place on cold cathode surfaces in vacuum arc determine operating modes of high-voltage diodes of high-current pulse electron accelerators, electric low-pressure arc. These phenomena were completely described in [1-3]. The mechanism leading to intensive increasing in vacuum current and appearance of a high-voltage vacuum breakdown is the explosive electron emission (EEE), the active centers of which are micronibs on the cathode surface.

A characteristic feature of the electric breakdown is the presence of a cathode material drop fraction (aerosol microparticles) in the discharge filament. The drop fraction part enlarges with increasing pulse duration and under hundred nanosecond duration it tends asymptotically to value determined under investigation of the semistationary vacuum arc (50–80 %)[4-8]. The particle diameters are 10^{-8}-10^{-6} m. The distribution function maximum is on the particles which correspond to the electron free run length in a cathode material [9]. The liquid phase aerosol particles carry not only material, energy but electric charge too. They emit the electrons heavily. Supposition about probable existence of positive charged particles in the electric arc cathode region which arises as a result of overcharging and under influence of ion current in the ion production zone was given in [10]. After generation the particle movement to the cathode is possible. We can not exclude another models of positive aerosol particle generation near the cathode surface.

As a result of EEE development the dense plasma is formed that leads to the electrostatic shielding of cathode micronibs and to decreasing the electric potential gradient at the surface. It happens because micronib characteristic sizes ($3-20\cdot10^{-6}$ m) are considerably more (on several degrees) then the Debay shielding radius and length of cathode region of potential fall in dense plasma cathode flame. Therefore, the micronibs influence, as emission centers, becomes insignificant at this stage of vacuum arc and low-pressure arc.

In this case the abnormal high cathode emission can be caused by individual fields of some particles. The individual ion fields were taken into account in [11, 12], that essentially improves emission conditions, but the life time of fluctuation is insufficient for considerable growth of emission current due to small ion mass in comparison with a mass of aerosol particles.

In this connection it is of interest to investigate the influence of positive aerosol particles on emission characteristics of cold cathodes in an electrical vacuum arc [13].

Under initial condition we consider a cold metallic cathode located in an external electric field $\vec{E}_0$. The electrons of metal are in the rectangular potential well. But because of $\vec{E}_0$ (in correspondence with the Shotki effect) and electron "image force" the well wall is faced on the vacuum warps and as a result it transforms into the potential barrier of a finite width. Electron emission in vacuum becomes possible due to the tunneling effect. Taking into account the positive charged aerosol microparticle warps potential barrier additionally and facilitates conditions for emission.

Let us consider the equation for the electron potential energy. In Fig. 1 the case is shown, at which a microparticle with charge Q and radius R is on the distance d from the metallic surface.

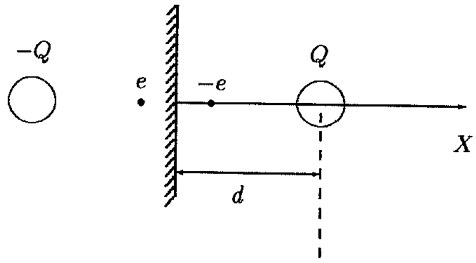

Fig.1. Interaction of an emiting with mirror image and microparticle.

Let the coordinate axis X is directed from the metallic surface to vacuum trough particle center. Zero point is located at the metal surface. Hereby, particle movement will take place in the area with $x > 0$. One-dimensional movement along axis X is shown in Fig.2. We suppose that electrons in metal are described by free electrons model and they move in the one-dimensional potential box of a depth $V = -V_0$. The chemical potential level is μ and at $T = 0$ it coincides with electron energy on the Fermi surface. At the selected zero point it is reasonable to name $|\mu|$ as a work function without external fields. Let δ is equal to the size of near-surface region (transition region) where the "image force" formation takes place. At a distance $x < \delta$ the conception of "image force" is not valid. When $x > \delta$ the electron potential energy has the form:

$$U(x) = -\frac{e^2}{16\pi\varepsilon_0 x} - eE_0 x - \frac{eQ}{4\pi\varepsilon_0 |d-x|} + \frac{eQ}{4\pi\varepsilon_0 |d+x|} + U_d(x) \qquad (1)$$

where ε_0 is the electrical constant,

$$U_d(x) = \begin{cases} -eE_0R^3\left(\dfrac{1}{(d+x)^2} + \dfrac{1}{(d-x)^2}\right) \\ \qquad x \le d - R \\ -eE_0R^3\left(\dfrac{1}{(d+x)^2} - \dfrac{1}{(d-x)^2}\right) \\ \qquad x \ge d - R \end{cases}$$

The first member in the (1) is potential energy of interaction between electron and its electrostatic mirror reflection, the second – potential energy in the external field, the third and fourth – potential energy of interaction with charged conductive globule and its mirror reflection. $U_d(x)$ - potential energy of interaction between electron and electric dipole field induced by external field $\vec{E}_0$ in charged conductive globule and its mirror reflection [14]. Since particle is a conductor, hereinafter we shall suppose that the potential energy inside of particle will be identical and is equaled to a sum of potential energy on surfaces U_k and depth of potential box in metal.

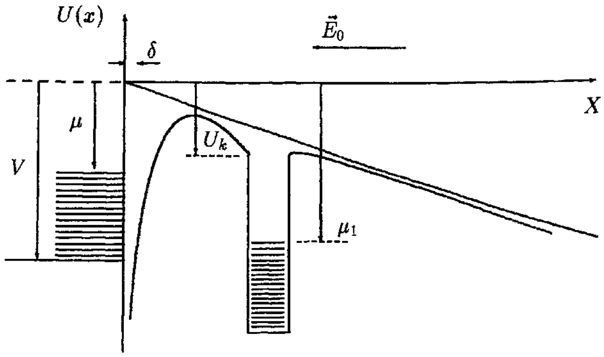

Fig.2. The potential energy and scheme of energy levels in view of microparticle.

In a Fig.2 the characteristic graph of an potential energy dependency, defined equation (1), and system of power levels at the left in the cathode material, on the right in a drop schematic is shown. Thus on the graphs of Fig. 2 deformation of potential barrier and shift of energy levels in microparticle is graphically presented.

In Fig. 3 graphs of potential energy dependency from x under various values of a distance of a microparticle from the metal surface is presented. From Fig. 3 it is visible that the most powerful deformation exists under small d. Herewith, it is noticeably reduction of height potential barrier.

Let us consider the microparticle influence with taking into account the deforming of electron potential energy on emission features of cold cathode.

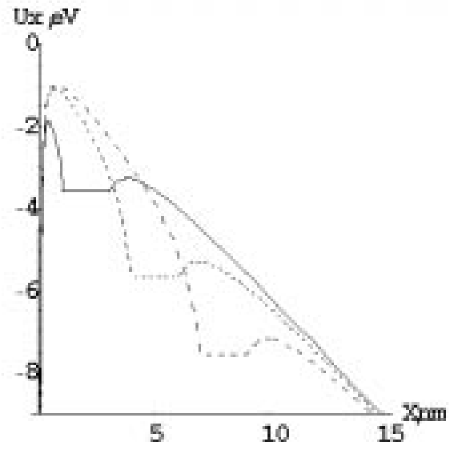

Fig.3. The potential energy dependency $U(x)$ at $E_0 = 0.6 \cdot 10^9 \, V/m$, $Q = 2e$, $R = 1$ nm for $d = 2, 5, 8$ nm.

We calculate the density of autoemission current j_a, as a product of current density of electrons hitting the inner metal surface, on transmission coefficient (with following integration):

$$j_a = e\int_{\mu_1}^{\mu} D(E)\, j_i(E)dE, \qquad (2)$$

where e is elementary charge,

$$D(E) = \exp\left(-\frac{2}{\hbar}\int_{x_1}^{x_2}\sqrt{2m(U-E)}dx\right) \qquad (3)$$

is the transmission coefficient, $j_i(E)dE$ is the density of electron flow falling on the surface with the energy from E to $E + dE$ [16], $\hbar$ is the Plank constant. We suppose that if inside the globule the vacant energy levels are present, i.e. $E > \mu_1$, then the electrons flowed from the metal can get through it without hindrance. So, it is necessary to integrate (2) from the energy $\mu_1 = U_k - |\mu|$, if $\mu_1 > -V_0$, otherwise let's assume $\mu_1 = -V_0$.

At $T = 0$

$$j_i(E)dE = \begin{cases} \dfrac{4\pi m}{h^3}(\mu - E)dE, & E \le \mu \\ 0 \;, & E > \mu \end{cases} \qquad (4)$$

The results of numerical calculations under formula (2) with taking into account (1, 3, 4) are provided in Table1 for various values of the external electrical field. In the last lower line the calculation results are represented without microparticles. Herewith, values of the potential energy inside of metal, chemical potential, radius and charge of globule were taken equal to following values: $V = -11$ V, $\mu = -4$ eV, $R = 1$ nm, $Q = 8e$. From Table1 is followed that the main influence on autoemission is exerted by the electrical field.

Table 1

E_0,V/m	$0.2 \cdot 10^9$	$0.6 \cdot 10^9$	$0.8 \cdot 10^9$
d, nm	j_a, A/m^2	j_a, A/m^2	j_a, A/m^2
2	$1.74 \cdot 10^{-55}$	$1.1 \cdot 10^{12}$	$2.58 \cdot 10^{12}$
3	$7.16 \cdot 10^{-45}$	$3.8 \cdot 10^{8}$	$1.71 \cdot 10^{9}$
4	$1.57 \cdot 10^{-105}$	$6.53 \cdot 10^{-26}$	$7.44 \cdot 10^{-10}$

However it is seen that the presence of the globule near the electrode surface also leads to significant increasing of the autoemission current, which by several orders of magnitude exceeds the thermoemission current under $T = 3000$ K: $j_T = 8.2 \cdot 10^7 \; A/m^2$.

The Table 2 shows the influence of the positive charge value of microparticle ($R = 1$ nm) on the current value at $E_0 = 0.6 \cdot 10^9$ V/m. It is obviously that increase of Q leads to significant enhance of autoemission. Herewith, the significant current density (exceeding thermoemission current) is reached under $Q > 4e$.

Table 2

	$Q = 2e$	$Q = 4e$	$Q = 6e$
d, nm	j_a, A/m^2	j_a, A/m^2	j_a, A/m^2

2	$9.0 \cdot 10^{-4}$	$5.7 \cdot 10^{8}$	$1.1 \cdot 10^{11}$
3	1.65	$9.08 \cdot 10^{4}$	$1.12 \cdot 10^{7}$
4	$2.0 \cdot 10^{-4}$	1.76	$6.69 \cdot 10^{2}$

Thus from results obtained we can conclude that the presence of positive aerosol microparticles of submicron range can have important influence on emission characteristics of cold cathodes.

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