ON RELATION BETWEEN THE AUTOEMITTER TOP FIELD, ANODE VOLTAGE AND CATHODE GEOMETRY

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A field emission diode has been made up on the basis of a flat metal anode and pin cathode (of the height *a*) that is mounted on a flat metal plate parallel to the anode. The potential of the field emission diode has been calculated as the function of the pin cathode shape, its height, the anode-cathode potential and the potential value into cathode. It has been shown that the potential barrier transparency possesses a nonlinear dependence on the anode potential in the Fowler-Nordheim coordinates, if the cathode height (*a*) is less than 1000 nm. To obtain a measurable field emission current, the following condition should be met: $F_{mid}\cdot a>\varphi$, were F_{mid} is the macroscopic field strength within the anode-cathode spacing, and φ is the pin cathode work function. Therefore, to get the field emission current, either the field strength should be $>10^6$ V/cm, or another field source should be used in addition. For example, the contact electrode potential between the pin part of the cathode and its base can provide such a field source. An analytic function was derived for the electric field of a pin cathode located on a flat substrate.

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1. INTRODUCTION

The field value of autoemission cathodes has not been measured. Calculated estimations are rather rough. In the case of metals, the field is in a linear dependence on the anode voltage [1]. For semiconductor cathodes, these estimations are complicated with the voltage drop inside the cathode [2], which results in non-linearity of current-voltage characteristics [3, 4] and, as a consequence, in nonlinear field dependence on the voltage [5, 6].

Currently investigated are the systems of metallic and semiconductor cathodes with micrometer and sub-micrometer sizes [7]. Thereof, estimation of the field for these systems seems to be topical.

This work is devoted to the dependence of the external field on linear dimensions, shape of cathodes and potential drop on them.

2. THE DIRICHLET TASK FOR THE LAPLACE EQUATION

The electrostatic field potential inside a closed domain is expressed via known potential values at its boundary with the following formula:

$$U(M)=\int_S U_S(N)\cdot\frac{dG(N,M)}{dn_S}\cdot dS_S, \qquad (1)$$

where U(M) is the potential in internal points of the region, $U_S(N)$ – potential values at the boundary, G(N,M) – Green's function of the Laplace operator for the S region.

Let us consider the electrodes by the way of two parallel metallic planes with the cathode shaped as a pin of the height a. The potential between electrodes can be expressed by the following sum

$$U(M)=U0(M)+UE(M)\ ,\ U0(M)=F_{mid}\cdot z\ .(2)$$

Here, U0(M) is the potential between metallic planes, the field of which is F_{mid}; UE(M) – potential of the pin cathode itself that enhances the field near its top. The potential U0(M) at the pin surface S_N is U0(N). If the cathode potential $U_C = 0$ (metallic cathode), and the anode one $U_A<0$, then

$$UE(M)=\int_{S_N} U_{S_N}(N)\cdot\frac{dG(S,M)}{dn_S}\cdot dS_S, \qquad (3)$$

where at the pin surface $U_{S_N}(N)=-U0(N)$, and in the rest parts of the surface S_A, S_C, $U_S(N) = 0$.

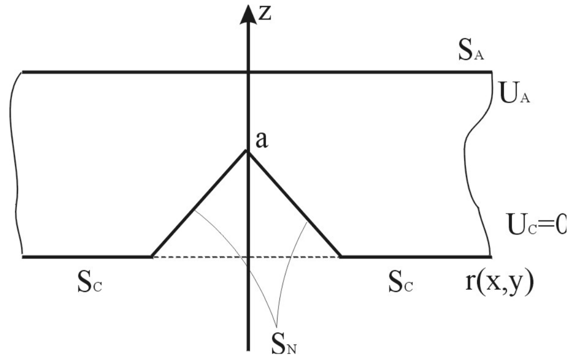

Fig. 1. The scheme of an autoelectronic emitter (pin with rounded top) on a metallic plane. The internal surface of the autoelectronic diode is $S = S_A + S_C + S_N$

Let us introduce relative coordinates $\xi = z/a$ and $\eta = r/a$. The potential and integral are expressed in dimensionless coordinates normalized by the pin height. Derivates of $UE(M)$ with respect to dimension coordinates are equal to the product of derivates with respect to dimensionless coordinates and *a*. In the case of a metallic electrode, $f(\xi)=\xi$ within the interval $0<\xi<1$.

At the surface of a semiconductor cathode, the potential is not equal to zero. In the absence of contact voltages between the pin and metallic base, it is the most probable that

$$k\cdot\xi\le f(\xi)\le\xi, \qquad (4)$$

where k < 1. When the contact potential takes place, *f(ξ)* is added with its value normalized by the expression $F_{\text{mid}}\cdot$a. It means that with decreasing the height of the semiconductor cathode the potential near its surface in vacuum can be considerably changed even for equilibrium bend of bands. Thus, the formula (3) describes the part of the potential that creates the field of a high strength near the autoemitter top. From the physical viewpoint, this field is created by charges on the pin charges of the opposite sign on flat parts of the cathode band anode, the amount of which being equal to that on the top. In the considered by us system of flat electrodes, when removing the anode to the distance considerably exceeding the pin length, the charges on the flat part of the cathode surface are a mirror image of pin charges in the cathode plane. It is obvious that the autoemission field is mainly created by charges located on the cathode pin part. Its value is in proportion to the voltage drop along the pin length, which is created by the uniform field existing between the electrodes. Besides, the voltage of the uniform field along the cathode length should exceed the work function. Only in this case after the turning point from the vacuum side there will be free electron states accepting carriers tunneling from the states of solid.

3. CALCULATION OF POTENTIALS AND BARRIER TRANSPARENCE FOR SOME CATHODE SHAPES

The potential barrier transparence was calculated using the formula from the work [8]. The pin shape on Fig.2, express by when the function equal 0:

$$uc(r,z) = F_{mid} \cdot z + q \cdot ut(r,z,a,b,\delta,g,) . \qquad (5)$$

The function $ut(r,z)$ is the potential of the charges on the axis z between dots $0 < ad < \varsigma < ae < a$ which the linear density $\rho(\varsigma) = p + g \cdot \varsigma$ ($\rho(ae) = 1$). The potential is equal to:

$$ut(r,z,a,b,p,g,) = \int_{ad}^{ae} \rho(\varsigma) \cdot \left[\frac{1}{R1(r,z,\varsigma)} - \frac{1}{R2(r,z,\varsigma)} \right] \cdot d\varsigma, \qquad (6)$$

$$R1(r,z,\varsigma) = \sqrt{r^2 + (z-\varsigma)^2} \text{ , } R2(r,z,\varsigma) = \sqrt{r^2 + (z+\varsigma)^2} .$$

This integral are evaluated by a primitive functions (the final express so bulky unfortunatly) The cathode (1) repeats the shape of an elongated spheroid with the height *a*, base radius *b (b < a)*, and top radius of curvature *da*. The shape of the cathode changes in dependence on the system parameters (Fig. 2). However, for the same values of *a, b, da,* the field value near the cathode top is practically unchanged.

Fig. 3 illustrates the shapes of the cathode potential (1) and potential barrier (2) for an electron with account of the Shottky effect (3) as well as for the linear potential (2), the field of which is equal to that near the top F_{max}. This field is used in the Fowler-Nordheim formula. It is seen from the figure that the far turning point for the real potential is more removed from the cathode top than that used in the Fowler-Nordheim formula.

Account of the real potential results in essential departure of the voltage-current characteristic (Fig. 4) from the straight-line dependence in the Fowler-Nordheim coordinates (5). Differences grow with decreasing the cathode height (curves 4 to 1).

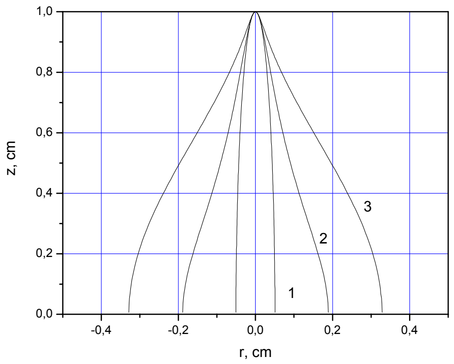

Fig. 2. Shapes of cathode pins with the radius of curvature for the top $4.5 \cdot 10^{-4}$ in units of the cathode length. (1) stands for the ellipsoidal and covering it curves when g = 1; (2) – g = 0.6, (3) – g = -1

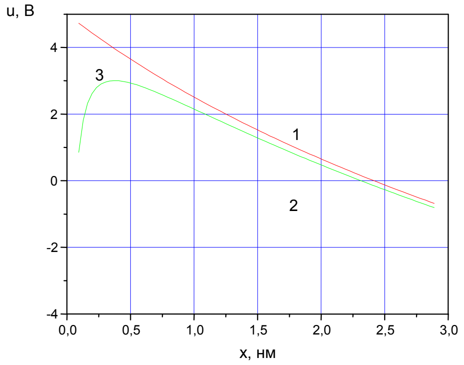

Fig. 3. The potential of the field near the surface of the ellipsoidal cathode. The dimensions of the cathode: a = 500 nm, b = 50 nm and da = 2.5 nm

The transparence of the potential barrier for the cathode with the height a = 300 nm decreases more than one order when changing the voltage on it from 0 to -1.5 V.

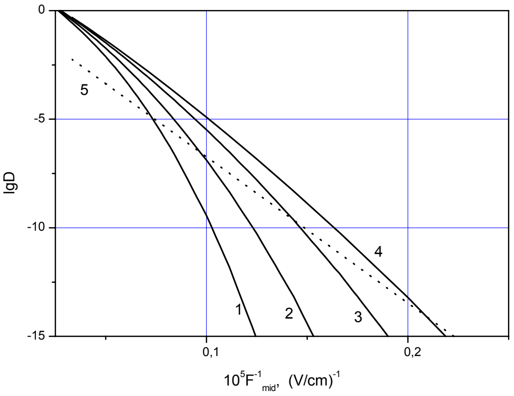

Fig. 4. The transparence of the potential barrier for various emitter heights a: (1) 1000 , (2) 500, (3) 250, (4)150 nm. The radius of the cathode base b = 0.1 a. (5) – transparence of the triangle potential barrier

Transfer of electrons from the solid cathode into vacuum requires the turning point to be located at the distance no more than several nanometers. Besides, the following condition should take place: $F_{mid} \cdot a \geq \varphi$, where φ is the work function for the pin cathode. This condition is realized when vacuum has free states with the energy corresponding to that of the Fermi level in the cathode. Thus, to obtain electron emission, the voltage drop at the height of the cathode top should be higher than its work function. The potential difference compared with this value can be obtained at the cost of the contact potential difference between the flat and pin cathode parts.

4. CONCLUSIONS

The following conclusions may be done:

1. When decreasing the cathode pin height *a*, the transparency of the potential barrier depends non-linearly on the anode voltage in the Fowler-Nordheim coordinates; some departures are noticeable when a < 1000 nm;
2. To obtain a measurable autoemission current, it is necessary for the voltage drop along the pin part of the cathode to exceed the work function value $F_{mid} \cdot a \geq \varphi$;
3. A field with the autoemission value can be obtained at the cost of a contact potential difference in the heterojunction emitter-substrate, if its value is higher than the work function one. It allows to understand the nature of light sensitivity inherent to autoelectronic and low-field emission;
4. Numeric estimations for the external field value in dependence of the voltage drop on the cathode are adduced;
5. Analytic formula for the electric field potential has been obtained.

It is possible that the light sensitivity non-limited by its threshold from the side of low frequencies is a result of rectifying the light wave field by the autocathode.

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О СООТНОШЕНИИ МЕЖДУ ПОЛЕМ У ВЕРШИНЫ АВТОЭМИТТЕРА, АНОДНЫМ НАПРЯЖЕНИЕМ И ГЕОМЕТРИЕЙ КАТОДА

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Рассчитан потенциал автоэмиссионного диода. Показано, что при уменьшении высоты острия катода (<1000 нм) прозрачность потенциального барьера зависит в координатах Фаулера-Нордгейма нелинейно от анодного напряжения. Необходимым условием автоэмиссии является неравенство $F_{mid} \cdot a > \varphi$, где F_{mid} – величина макроскопического поля, а φ – работа выхода катода. Таким образом, для получения автоэмиссионного тока из остриев необходимо либо высокое среднее поле между электродами (>10^6 В/см), либо дополнительные к внешнему источники поля. Такое поле может создаваться контактной разностью потенциалов между подложкой и острием. Получена аналитическая формула для потенциала электрического поля.

ПРО СПІВВІДНОШЕННЯ МІЖ ПОЛЕМ БІЛЯ ВЕРШИНИ АВТОЕМІТЕРА, АНОДНОЮ НАПРУГОЮ І ГЕОМЕТРІЄЮ КАТОДУ

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Розрахований потенціал автоемісійного діоду. Показано, що при зменшенні висоти вістря катоду (<1000 нм) прозорість потенційного бар’єру залежить в координатах Фаулера-Нордгейма нелінійно від анодної напруги. Необхідною умовою автоемісії є нерівність $F_{mid} \cdot a > \varphi$, де F_{mid} – величина макроскопічного поля, а φ – робота виходу катоду. Отже, для одержання автоемісійного струму з вістрів необхідно чи велике середнє поле між електродами (>10^6 В/см), чи додаткові до зовнішнього джерела поля. Таке поле може створюватися контактною різницею потенціалів між підкладкою і вістрям. Одержана аналітична формула для потенціалу електричного поля.