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Field emitters made of the contacted ytterbium and carbon nanolayers

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Abstract

The operation of field emitters of a new type prepared from contacted nanolayers of ytterbium and carbon has been investigated. The performed calculations and experiments allowed to optimize the emission characteristics of the emitters. The calculations took into account the existence of a transition zone between the layers of Yb and C. Emission characteristics of the cathodes including up to 40 pairs of layers of carbon and ytterbium with optimum thicknesses of 5 and 2 nm respectively were measured. The created multilayered emitters provide the average emission current density over the surface of the emitter up to 10–20 A/cm^2 and show promise for use in miniature electronic devices.

Keywords: Field emitter; Contact potential difference; Ytterbium; Carbon; Calculation; Experiment.

1. Introduction

One of the intractable problems of any field emitter is the need to obtain fields of the order or even more than $2 \cdot 10^7$ V/cm near their surface at moderate voltages. Earlier we have demonstrated the possibility of using the fields near the nanocontacts of materials with different work functions $e\varphi$ [1,2] for this purpose. Field emitters prepared from contacted layers of materials with greatly different work functions were developed. When first such cathodes were fabricated, thermal evaporation was used to create thin layers of contacting materials. This technology allows to make the emitters consisting of no more than three or four pairs of layers with different work functions. It is obvious that to obtain intensive field emission we are bound to have a system with a large number of pairs of layers and to collect current from such a layered cathode. In this paper, we report the results on the development and investigation of multilayer cathodes including up to 40 pairs of layers with varying work functions.

2. Numerical computations

We present here the calculation data obtained for the structure prepared from ytterbium (Yb, $e\varphi = 3.1$ eV) and carbon (C, $e\varphi = 4.7$ eV) layers.

Calculations necessary to optimize the layered field emitters and determine their emission characteristics have been carried out using the Comsol software.

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Electric fields, electron trajectories, current density distributions over the surface of the field emitter and emitter currents were found. The calculations took into account the existence of a transition zone between the layers of Yb and C, where the mixture of these materials exists [3]. The current to the anode was determined by the Fowler–Nordheim equation (see for example [4]).

Emission of the layered cathode is conditioned by the fields that exist due to the difference in work functions of contacted materials, as well as by the 'external' field associated with the supply of voltage U_a between the cathode and the anode. The distribution of the potential $U(x)$ in the transition zone due to the difference in the work functions of contacted materials was described by the function:

$$U(x) = 3.1 + 1.6 \cdot \cos\left(\frac{\pi}{2} \cdot \left(\frac{x}{l}\right)^{A1}\right)^{A2},$$

where l is a width of the transition zone.

The shape of this distribution can be varied by changing the coefficients $A1$ and $A2$. The coefficients were chosen so as to ensure the best possible agreement between the calculation and the experimental results on the emission characteristics of the layered cathode.

Fig. 1, *a* schematically shows the contact region of adjacent Yb and C layers. The vertical dashed lines indicate the boundaries of the transition zone between the layers. Fig. 1, *b* demonstrates typical distributions (used in the calculations) of the potential U and the total electric field E in the contact area defined at $U_a = 6$ kV and the given value $\Delta e\varphi = 1.6$ eV of the work function difference for these layers in the diode with a gap of 1 mm between the cathode and the anode. Typical electron trajectories (*e*) are shown in Fig. 1, *a* as well.

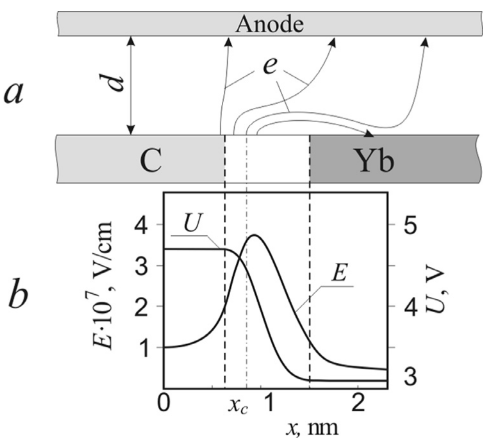

Fig. 1. Schematic representation of the problem statement: a region of the diode system (*a*) and the distributions of potential U and electric field E near the contact between the Yb and C layers (*b*) Trajectories of the electrons *e* are shown; *d* is a distance, x_c is a position of the critical point.

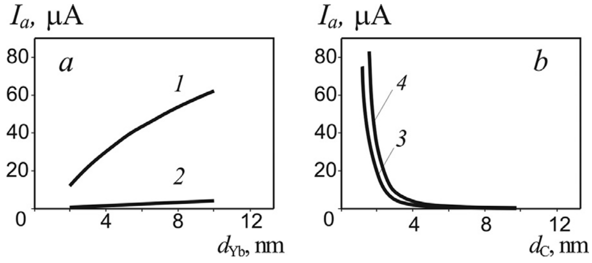

Fig. 2. Plots of the anode currents versus thicknesses of Yb (*a*) and C (*b*) layers at two values of the C (*a*) and Yb (*b*) layer thickness $d_{C,Yb}$, nm: 2 (*1*), 5 (*2*), 3 (*3*) and 5 (*4*). The calculations were performed at $U_a = 6$ kV.

As follows from the calculation results of electron trajectories, electrons emitted by the cathode region $x \le x_c$ reach the anode at a fixed voltage U_a, whereas those from the region $x > x_c$ return to the cathode at the same voltage.

The performed calculations revealed that the anode current of the layered cathodes depends on the thickness of the contacted layers. Typical calculated dependencies of the anode current I_a upon the thickness values of the ytterbium (d_{Yb}) and the carbon (d_C) layers are shown in Fig. 2.

According to the information in literature (see for example [3,5]), the width of the transition zone is typically about 0.6–0.8 nm. Therefore, we can probably take $d_C =$ 1–2 nm as the optimal thickness of a carbon layer, as it is only a little more than the transition zone dimension. Thickness d_{Yb} of the ytterbium layers should be much more, and may be taken, for example, as about 5 nm.

Two current-voltage characteristics of the cathodes including 20 pairs of Yb–C layers are shown in Fig. 3. The former was obtained for optimal thickness values

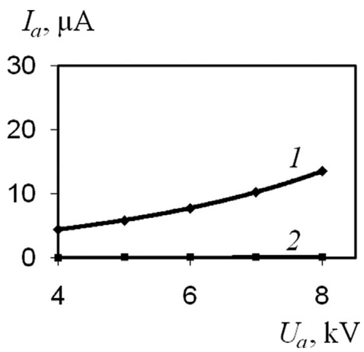

Fig. 3. Calculated current-voltage characteristics for the emitter with 20 pairs of layers structure with $d_{Yb} = 5$ nm, $d_C = 2$ nm (*1*) and $d_{Yb} = 2$ nm, $d_C = 5$ nm (*2*).