Studying electric field enhancement factor of the nanostructured emission surface

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Abstract. Mathematical model of nanostructured field emission surface is proposed. In order to determine geometrical parameters of the surface structure digital processing of scanning electron microscopy images was used. Effective value of local electrical field enhancement factor is defined and calculated within the Fowler-Nordheim theory. It was found effective enhancement factor decreases as the applied electrical field increases for a fixed geometry.

1. Introduction
The object of this study is field emission array, where microemitters are arranged in a rectangular lattice and have cylindrical shape with sharp top margin (Figure 1) [1-5]. Detailed analysis of the serrated microemitter blade in scanning electron microscope (SEM) revealed a multitude of sharp ledges with curvature radii of less than 10 nm that function as point field emitters with exceptionally large emission surface. This kind of nanolandscape naturally influences the distribution of electrostatic field and defines emission characteristics of the cathode. Example of such a nanolandscape is shown in Figure 1. The goal of this research is assessment of the level of influence of this nanolandscape onto the electric field near the surface. For achieving this goal it is necessary to solve the following problems: define the geometrical parameters of the surface nanolandscape, pick a numerical characteristic describing the influence of nanolandscape onto the fields close to the surface, construct a mathematical model of nanolandscape and compute the coefficient of field strength increase in terms of this model.

2. Model of field enhancement
For finding precise outlines in the images of nanolandscapes, different image processing algorithms were tested. The best results (Figure 1) were demonstrated by the method employing the discrete differential Sobel operator to calculate an approximate value of brightness in each point of the image. The processed images helped us to define the geometrical parameters of nanolandscape structure. The values calculated were the average curvature radius of tip defect of the surface, its height, distance between the tips and the angle at the tip.

The field gain coefficient characterizes the level of influence of the nanolandscape onto the electrostatic field distribution. The field gain coefficient is defined as \( \beta(s) = \frac{E_n(s)}{E_0} \), where \( E_n \) is the normal component of local field strength of nanostructure surface in point \( s \), \( E_0 \) is the strength of applied electric field on distance \( d \) from the surface without taking the nanolandscape into account.

Knowing the field gain coefficient at given point it is possible to compute the value of current density using the Fowler-Nordheim formula:

\[
j(\beta(s)E_0(s)) = \frac{A(\beta(s)E_0(s))^2}{\phi t^2(y)} \exp \left( -\frac{B \phi^2 y}{\beta(s)E_0(s)} \right),
\]

where \( \phi \) is the electron work function, \( t(y), v(y) \) are elliptic Nordheim functions.
Knowing the current density in area $S$ one can find the value of the current emitted from the surface. The general integral values of the current can be found as $I = \int_S j_{\beta(s)} E_0(s) ds$. In this formula, as opposed to “microproblem”, the area $S$ is in fact the complex surface of the nanolandscape. In order to simplify the calculations for finding out the emission current we’ve employed the effective value of field growth coefficient that equates the smooth surface of integrating in “microproblem” to the complex surface of “nanoproblem”: $I = \int_{S_0} j_{\beta_{\text{eff}}(s)} E_0(s) ds$.

Figure 1. The image of nanolandscape in SEM and after digital processing and pointing out geometrical non-homogeneities. The model of microemitters in the array and an area of emission surface with nanolandscape. Distribution of electrostatic field over the surface.

3. Conclusion
Thus use the effective value of field enhancement coefficient allows to take into account the complex geometry of surface $S$, but in the same time to simplify the computation by using its flat vertical projection $S_0$. It is discovered that with increase of field strength the effective growth coefficient decreases. This can be explained thus that the emission surface covers greater part of the nanolandscape surface $S$ while the smooth model surface $S_0$ remains constant.

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References
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