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THE MODELING OF LOW THRESHOLD FIELD EMISSION FROM NANOSTRUCTURES

***Lev M. Baskin[1], Pekka Neittaanmäki[2], Boris A. Plamenevskii[3]**

[1]Univ. for Telecomun.
Mojka 61, St.Petersburg
191196, Russia
lev_baskin@mail.ru

[2] Dep.Mathematical Inform. Technology
Jyväskylä Univ. Finland
pn@mit.jyu.fi

[3] Dep.Math.Physics, Physics Inst., St.Petersburg State University
plamrn@rol.ru

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ABSTRACT

Currently, there is considerable interest in field emission from thin carbon films and diamond-like structures as well as from systems containing fullerenes and nanotubes [1]. Such systems are likely to find wide application in the low-voltage cold cathodes, used as sources of electrons in electro-vacuum devices, primarily in flat displays providing images of high brightness. In all such systems the field emission is initiated by anomalously small fields.

The field required to produce a measurable current is of order of 0.1 – 50 V/μm. This is 3 to 4 orders of magnitude smaller than the threshold field needed to produce emission from metallic samples. Another important feature is non-linearity of their current-voltage characteristics (CVC) in the Fowler-Nordheim (FN) coordinates. Also, in many cases there exists a CVC hysteresis effect, that is, the CVC may take different shapes depending on whether the voltage increases or decreases. Finally, the emission characteristics are dependent of the thickness of the film. It is likely that all above properties are not unique to the carbon-based structures, and are typical for a broader class of systems, including emitters based on broad band semiconductors [2,3].

There several questions one needs to answer in order to explain such emission properties:

a) What is the emission mechanism, and why are the fields causing the emission so small?
b) What brings electrons into the film and what are their transport properties?

The mechanisms usually discussed either involve negative electron affinity, or the presence of hot electron emission. However, the two mechanisms cannot describe the full range of experimental evidence, and often contradict the experiment.

In the present work, we suggest a physical model of the electron emission that enables to answer the both above questions. To heuristically justify the model, we make use of some simplified mathematical models. Whereas the first question admits a simple model, a realistic mathematical model of the electron transport near the surface would apparently require invoking multiscale methods.

By means of the mentioned simplified model we have shown that in all such structures emission current is limited by the bulk charge of the electrons injected into the emitter. For the low conductivity structures (such that the width of the Debye layer ex-

ceeds 1 nm) the field at the surface is determined not only by the voltage applied, but also by the fields of the charged localized impurities located in a thin (0.2 - 1 nm) layer near the surface.

This model explains a number of such observed features, as the proportionality of the emission current to the inverse square of the film's width, the hysteresis phenomenon, arising due to charging of deep traps and changing the field strength at the surface. Finally, the small threshold fields are explained, as one recalls that external field is required to transport electrons across the film, rather than to create a field at its surface.

There several mechanisms leading to creation of local fields.

1. The presence of dipole impurities (molecules) in the surface layer. Due to polarization of such molecules the surface field in some micro regions may have field emission sign and exceed 10^7 V/cm. Thus, the surface will acquire a positive potential, which will facilitate supply of electrons from the bulk. Such emission would have a pronounced 'spotty' structure. The modeling shows that the number of microspots is proportional to $N^{2/3}$, where N is the concentration of the impurities. It is likely that such molecules are concentrated near the grain boundaries, which explains the drop in emission voltage for the nano-crystal surfaces.
2. For nanotubes, the local fields can be linked to the microgeometry of the surface tubes. In quantum wire-like structures, electrons can be trapped in so-called trap modes, i.e., discrete localized states. Such states may exist near the bends or in places where a quantum wire broadens. As electrons propagate along the wire, the trap modes are filled. The charge localized in such a mode may create large fields in the same wire, as well as in the adjacent wires. The same effect occurs when an electron wave is reflected off a sharp bend. A decrease in the group velocity and associated increase in the electron density may, in this case, produce large local fields.

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