Interpretation of dynamic and dc field-emission characteristics of nanocarbons in terms of two-stage emission model

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Different nanostructured carbons demonstrate notable electron emission in low-magnitude electric field. In the case of nanotubes and fibers, this feature is associated with field focusing at sharp tips. For other materials, with relatively smooth surface morphology, the actual mechanism of emission enhancement remains unclear. Being different in many aspects, most efficient emitters of this type do have common features: 1) their surface layer is heterogeneous, includes both sp^2 and sp^3 grains and/or numerous structural defects. 2) work function values derived from emission I-V plots in accordance with Fowler-Nordheim (FN) formula (0..1.5 eV) prove to be much lower than ones determined with other methods (optical or thermionic emission) and than values generally typical for carbon (>4 eV). Different authors consider field-induced emission from such materials as a two-stage process involving transient acceptor-type states in the surface layer – for instance, conduction band states of a diamond-like film or grain. Now, we apply this two-stage model to the results of experimental study on emission from nanocarbons in non-stationary (pulsed) field [1,2]. Both digital and analytical modeling confirmed that the emission hysteresis observed in the experiments can be explained via dynamics of electron population at transient states. To simulate modification of I-V plots with variation of field pulse parameters (amplitude, dc bias, pulse shape and length) and with emitter activation/degradation, the coulomb field of electrons at the surface states had to be put into account.

The developed model allowed us to associate parameters of dynamic and static I-V plots with emission centers' properties. For a sufficiently short field pulse, when the surface charging effect is negligible, the direct (measured at the field increase) I-V plot branch follows the FN law with the slope determined by the material work function. The inverse branch has much lower slope determined by the peak field achieved earlier in the pulse. In static regime (dc or long pulse) both branches coincide, and their inclination to the axis in FN coordinates gives us the value of surface electron affinity (conduction band bottom energy – for emission via a diamond like phase inclusion). In our experiments, the static and the dynamic direct branch slopes' ratio was about 1:3, which corresponds to sensible values of 4.5 eV for work function and ~3 eV for the transient layer material band gap.

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[2] A.V. Arkhipov, M.V. Mishin, I.V. Parygin. *Surf. Interface Anal.* **39**, 149 (2007).