Field emission properties of carbon nanotube arrays grown in porous anodic alumina

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Carbon nanotubes (CNTs), with their excellent electronic properties and extremely high aspect ratio, represent an ideal material for building electron sources based on field emission [1]. The field emission phenomenon, especially from single or isolated tips, is quite successfully represented by the Fowler-Nordheim equation. However, such model often fails the attempt to describe the field emission from populations of CNTs and the comparison with experimental data is usually in disagreement with expectations. Such discrepancies arise when considering large numbers of CNTs, where collective effects are present and influence the measured I–V characteristics. In this case, questions concerning the enhancement factor dependence on the tips density or the space charge effect can be studied only if emitters have quite uniform height and density. In this work we study the emission properties of multi-wall CNTs grown within anodic alumina templates. For such materials the source can be modelled as an ordered and uniform array of emitters and theoretical predictions can be compared with experimental measurements in a direct way.

The alumina template was obtained by electrochemical anodization of an iperpure aluminum foil, in oxalic acid solution 0.3 M, at 40 V d.d.p. and 5 ^{o}C, obtaining a regular honeycomb-like structure with pores diameters and pitch of 60 and 100 nm respectively [2]. The growth of vertically aligned CNTs in the alumina template is obtained by catalyst-assisted CVD, after the electrochemical deposition of cobalt seeds in the bottom of the alumina pores. CVD was performed at atmospheric pressure in a quartz hot wall furnace, warmed up to 700 ^{o}C, where a 1 hour annealing in H_2 flow was followed by a 30 min deposition step, in a 15 % C_2H_2 gas mixture in N_2. Typical morphology of the obtained CNTs in porous alumina is shown in Fig. 1.

Field emission measurements were performed in a high vacuum chamber (10^{-7} mbar) equipped with micrometric translators to move the sample along the three axes [3]. The distance of the anode from the flat cathode (sample) and the position in the (x,y) plane are PC-controlled with a minimum incremental step of 0.1 µm in the x-y plane and 1 µm in the z-direction. The effective anode-cathode distance is determined via the measurement of the anode-cathode capacitance and the current is measured with rms noise of about 1 pA. Typical field emission current density curves as a function of the applied electrical field are shown in Fig. 2. Experimental results prove that CNT matrices can produce quite high and stable current densities.

Simulation of the emitters array, by mean of the COMSOL Multiphysics software, was used to calculate the electric field dependence on different CNTs geometries (height, interspacing, apex shapes, etc.) and to predict the corresponding field enhancement factors. Comparison between the experimentally measured field enhancement factors and the expected values are discussed.

References

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Figures:

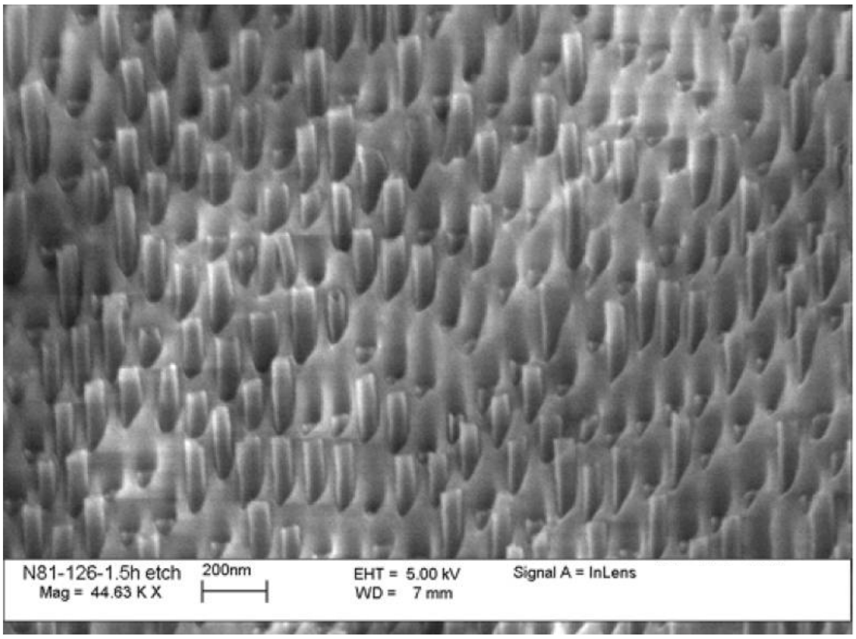

Fig.1 Matrix of multi-wall CNTs within alumina template

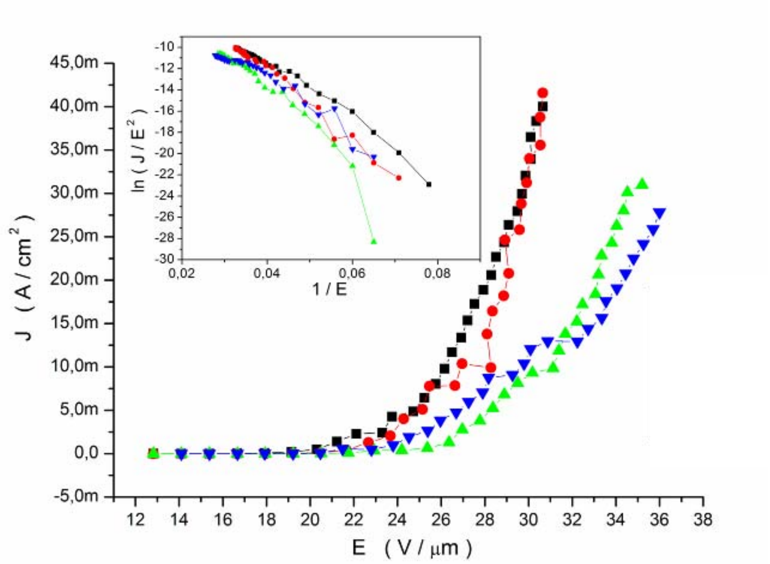

Fig. 2 Current density vs. the external electric field.
The inset shows the representation in the Fowler-Nordheim plane.