ELECTRICAL PROPERTIES OF CARBON NANOTUBES PROBED BY ELECTRIC FORCE MICROSCOPY

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In this work electric force microscopy (EFM) has been successfully applied to study the electrical properties of single- and multiwalled carbon nanotubes (SWNTs, MWNTs). Electrostatic properties of separated carbon nanotubes deposited on a dielectric (SiO_2) layer have been investigated by charge injection experiments [1,2] (see Fig.1) using a Multimode/Nanoscope IIIA AFM (Digital Instruments) under dry nitrogen.

We found that upon local injection from the biased EFM tip, charges delocalize over the whole nanotube length, *i.e.* 1-10 µm (see Fig.1), consistent with a capacitive charging of the nanotube when biased with respect to the substrate by the EFM tip. Two different types of behaviors for the injected charge have then been observed. First, a long-retention behavior (with retention time of hours under dry nitrogen). Second, the occurrence of sudden nanotube discharges during the acquisition of EFM images, in single or in multiple steps, associated with specific defect points on the nanotube (see Fig.2). In addition, for the nanotubes exhibiting abrupt discharge behaviors, the SiO_2 substrate is shown to act as a charge-sensitive plate for emitted electrons, thus allowing the spatial mapping of MWCNT field emission patterns (see Fig.3).

These electrostatic properties of MWCNTs (charge storage and density, charge stability and instabilities, enhanced electron emission at the nanotube caps) will be discussed as a function the diameters of the MWCNTs, of intershell tunneling [3] and field-emission effects.

References:

[1] M. Zdrojek, T. Melin, C. Boyaval, B. Jouault, M. Wozniak, W. Gebicki, A. Huczko, D. Stievenard and L. Adamowicz, accepted for publication in *Applied Physics Letters*.
[2] T. Mélin, H. Diesinger, D. Deresmes, D. Stiévenard, *Phys. Rev. Lett.* **92**, 166101 (2004).
[3] B. Bourlon, C.Miko, L. Forro, D.C. Glattli and A. Bachtold, *Phys. Rev. Lett.* **93**, 176806 (2004).

Figures:

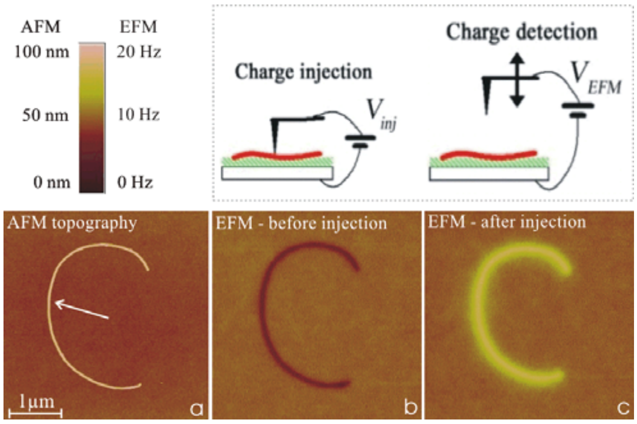

Fig.1 Inset : (left) Schematics of the charge injection with the tip biased at V_{inj} with respect to the substrate; (right) EFM data acquisition, consisting in recording of the cantilever resonance frequency shifts, when biased at V_{EFM}; (a) Atomic force microscopy topography image of a ~30 nm MWCNT. The scale bar is 1 µm. The white arrow indicates the injection point; (b) EFM image of the uncharged nanotube (20 Hz color scale); (c) EFM image after charge injection (V_{inj}=-3V for 2 minutes). No significant discharge was observed while scanning the same MWCNT continuously for 10 hours.

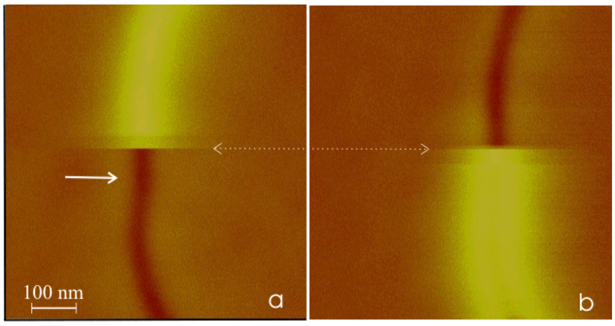

Fig.2 EFM images of the nanotube of Fig. 3 (topography not displayed here) arround the injection point indicated by the solid arrow. The injections in (a) and (b) were performed at the same point. Scans were acquired from top to bottom in (a) and from bottom to top in (b), showing that the abrupt discharge observed in both cases is related with a specific point of the MWCNT. The dashed line is a guide to the eye for the correspondence between the two EFM images.

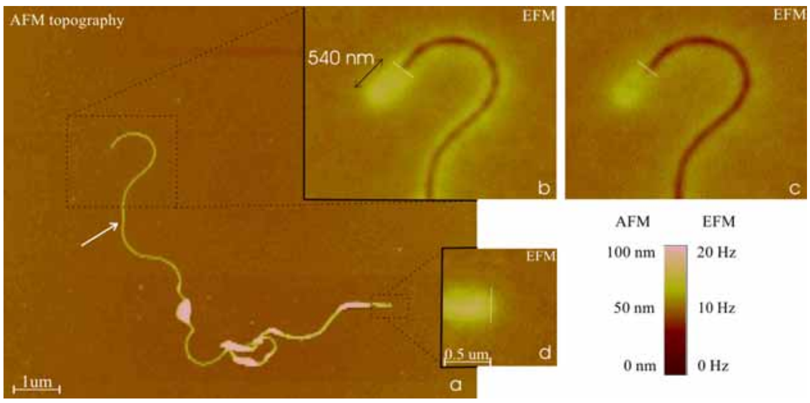

Fig.3 (a) AFM topography image of carbon nanotube before the injection experiment. The injection point is denoted by the white arrow. (b) EFM zoom-image on the smaller apex (~18 nm diameter) after injection of -6 V during three minutes and abrupt discharge. A bright halo is visible at the apex corresponding to charge emitted from the nanotube, while the discharged nanotube appears dark in the EFM image; (c) EFM image of the same cap 14 hours after injection; (d) EFM image of the other apex with bigger size(~ 40 nm) still exhibiting a charge, but no enhanced electron emission.