In situ measurements of the electrical and mechanical behaviour of carbon nanoscrolls

A.K. Schaper[1], H. Hou[2], M. Wang[3], Z. Xu[3], D. Golberg[3], and Y. Bando[3]

1. Material Sciences Center, EM&Mlab, Philipps University, 35032 Marburg, Germany
2. Chemistry College of Jiangxi Normal University, Nanchang, JX 330027, P.R. China
3. MANA, NIMS, Tsukuba, Ibaraki 3050044, Japan

schaper@staff.uni-marburg.de
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Carbon nanoscrolls (CNSs) are a special type of carbon nanotubes (CNTs) in that they do not consist of nested graphene tubes but are formed by rolling-up of a single (or a few) graphene sheet(s) [1]. While the chirality and structure of CNSs is well-documented, their electrical and mechanical behaviour is widely unknown in contrast to the one of nested tube structures [2,3]. Using the JEM-3100FEF transmission electron microscope (TEM) and the Nanofactory STM-TEM and AFM-TEM sample holders [4,5], we have performed *in situ* measurements of the electrical and mechanical properties of catalytically prepared CNSs and CNTs, in comparison.

The carbon material was synthesized in a catalytical process using Fe-phthalocyanine (FePc) as the precursor [6]. Fig. 1a) shows low-magnification micrographs of a selected measuring cycle with the tungsten probe tip contacting a single scroll at successive sites along the direction of decreasing tube length, Fig. 1b) shows a similar situation for a nested tube structure. On the right of each figure the current-voltage (*I-V*) diagram is shown monitoring resistances R ~ 7-10 kΩ for CNSs, and twice as large values for CNTs. The results obtained from a number of measurements provide clear evidence of a highly ballistic, superior conductivity of scroll structures and confirm the assumption that, in tubes composed of nested cylinders, only the outer few layers contribute to the electronic transport. Maximum current densities were determined at threshold currents up to 450 μA, and estimations were made of the resistances per tube lengths.

The mechanical properties of the above carbon structures were studied by repeated deformation cycles in tension and compression (Fig. 2a) while monitoring the bending force (Fig. 2b). Increasing the width of the cantilever movement stepwise through the range 100-500 nm, in all cases a rather weak mechanical response was found reaching maximum forces of 50 - 120 nN at a mean outer tube diameter ranging from ~20 to 60nm. Such soft mechanical behaviour was to be expected just with the scroll-type nanotubes. In some cases, fatigue behaviour was observed, buckling has been detected with nested tube structures only.

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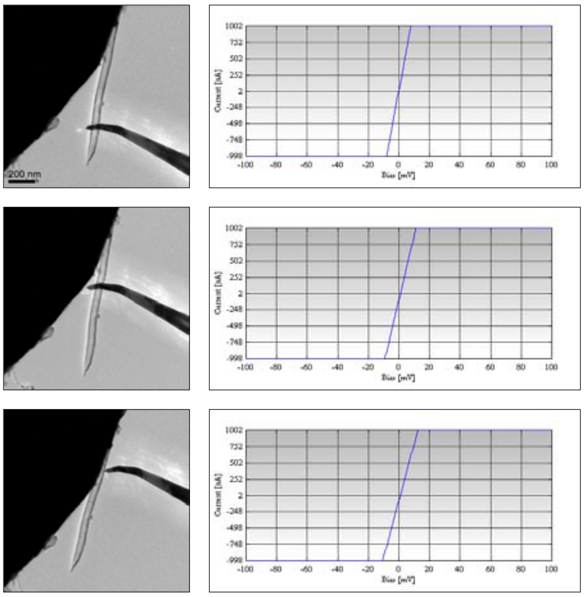
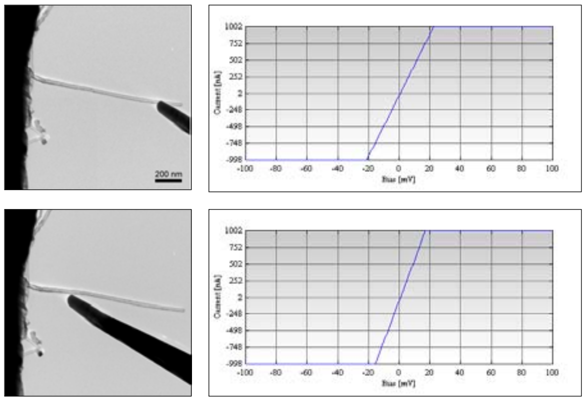
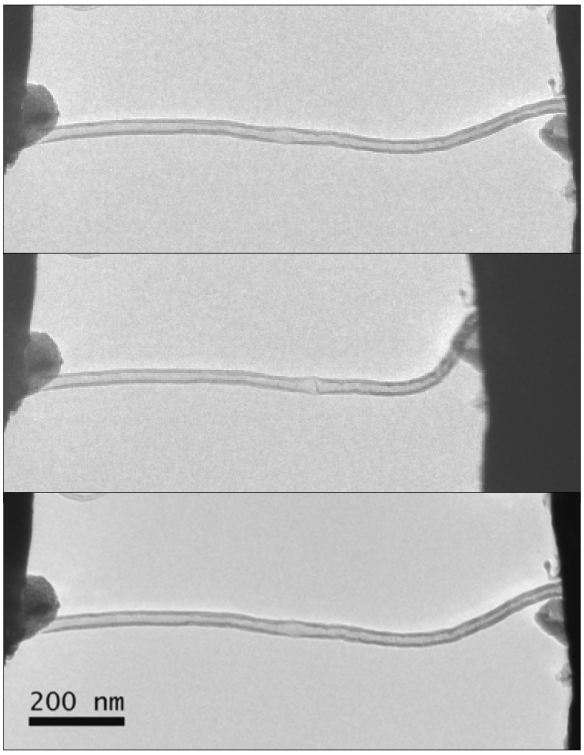


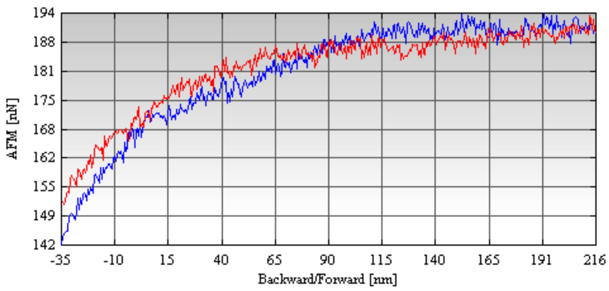


(b)

(a)

Figure 1. *In situ* measurements of the electric properties of CNSs (a) and of CNTs (b) in the JEM-3100FEF microscope: TEM micrographs and corresponding current-voltage (*I-V*) diagrams showing the different conductivity of both types of carbon nanostructures.





(b)

(a)

Figure 2. *In situ* measurements of the mechanical properties of CNSs and CNTs in the JEM-3100FEF microscope: a) TEM micrographs and b) corresponding load-elongation curves in compression (blue) and release (red) of a CNS.

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