NANOMATERIAL ELECTRICAL AND MECHANICAL PROPERTIES MEASURED IN A TRANSMISSION ELECTRON MICROSCOPE

Dmitri Golberg

Nanoscale Materials Centre, National Institute for Materials Science (NIMS),
Namiki 1-1, Tsukuba, Ibaraki, 3050044, Japan
World Premier International Centre for Materials Nanoarchitectonics (MANA), National Institute for Materials Science (NIMS), Namiki 1-1, Tsukuba, Ibaraki, 3050044, Japan

E-mail: GOLBERG.Dmitri@nims.go.jp

I will demonstrate the significant progress in electromechanical property measurements of diverse low-dimensional individual nanostructures, e.g. nanotubes, nanowires, nanobelts and nanocones, carried out inside a transmission electron microscope (TEM). The measurements were performed by means of two high-resolution field-emission instruments operating at 300 kV, namely JEOL-3000F and JEM-3100FEF, and on free-standing individual objects using specialized piezo-driven scanning tunnelling microscope (STM)-TEM and atomic force microscope (AFM)-TEM holders (with conductive or non-conductive cantilevers).

A sharp etched Au tip, acting as the STM tip, or a Si cantilever, as the AFM probe, was assembled within the holders. Individual low-dimensional nanostructures were mounted on thin metallic (Au, Al) wires (Ø 250 μm), Fig. 1 and Fig. 2, which then were driven in three dimensions (with a precision better than 1 nm) inside the pole-piece of the microscopes using a piezo-motor until a tight physical contact between a structure and the probe was achieved.

The successful experimental runs to be discussed include multi-walled BN (Figs. 1 and 2) [1-4] and N-doped C nanotubes (NTs) [5,6], ZnO nanorods and nanowires [7], double-walled CNTs, multi-walled CNTs filled with Cu [8], Au, CuI or ZnS, inorganic nanothermometers, e.g. liquid Ga-filled MgO NTs and In-filled SiO_2 NTs, CdS nanobelts, and BN nano- and microcones.

The current-voltage (STM-TEM, Fig. 1) and/or force-displacement (AFM-TEM, Fig. 2) curves were recorded under a full control of the nanomaterial morphological, crystallographic and chemical changes/modifications during all stages of probing/manipulation. This allowed us to clearly interpret many new intriguing physical, chemical and electromechanical phenomena peculiar to novel advanced nanostructures. These include, but are not limited to deformation-driven electrical transport and piezoelectricity in individual Boron Nitride NTs, time-resolved electrical transport in N-doped CNTs, rheostat-like behaviour, femtogram (Cu) and attogram (CuI) mass transports, nanopipetting in Cu- and Cu-halide-filled CNTs, and strength and elasticity modifications of nanoscale composite materials made of filled C nanotubes.

References

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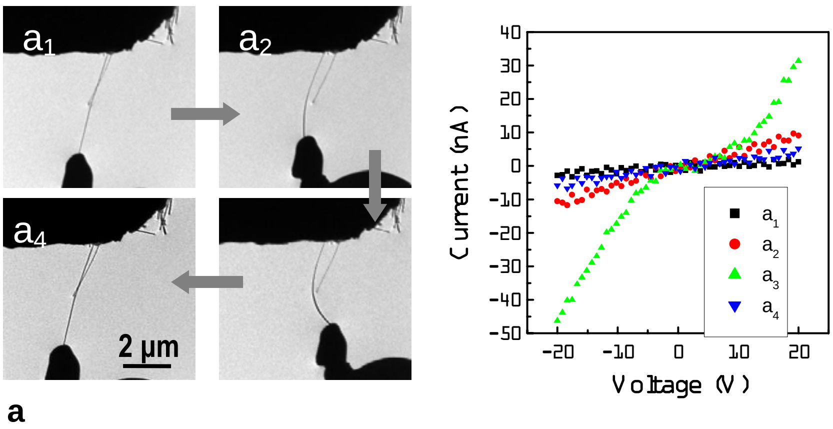

Figure 1. (a) Consecutive TEM images of an individual multi-walled BN nanotube bent inside HRTEM; and (b) the corresponding *I-V* curves recorded at different stages of the experiment (a_1-a_4). A notable current may pass through the nanotube in a bent state, while it disappears if the nanotube is straight; from Ref. [4].

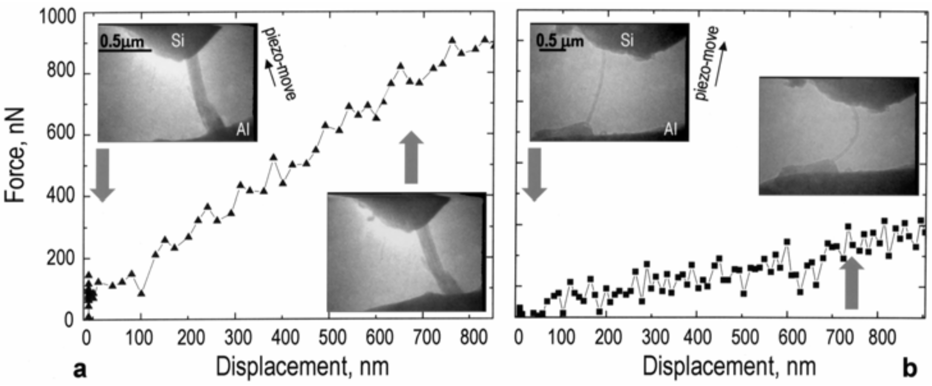

Figure 2. Force-displacement curves directly recorded on a relatively thick (a) and a thin (b) individual multi-walled BN nanotube using an AFM-TEM setup. The insets display the nanotube appearance at different stages of the experiments: from Ref. [2].