Nanotechnology Highlight

New Methods and Tools for Nanotechnology (9871874)

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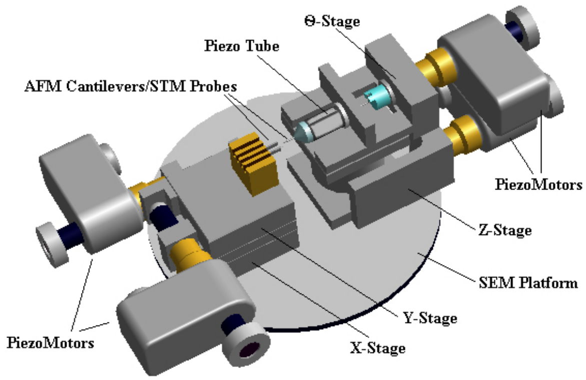
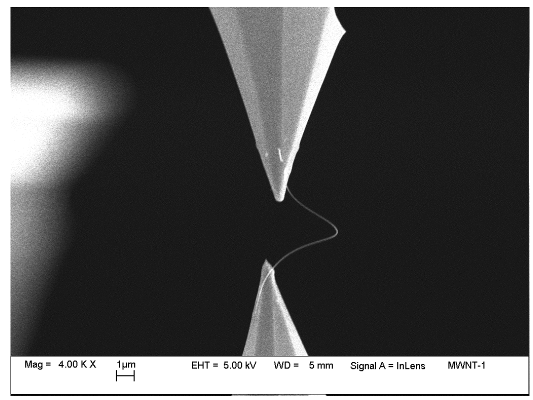
I. The home-built nanomanipulator (schematic left) has been used inside of a scanning electron microscrope to pick up, mount, and tensile load carbon nanotubes such as the individual multiwalled carbon nanotube shown attached between AFM cantilever tips (right image). We have reported on the breaking mechanism and tensile strength of MWCNTs [1], the tensile strength of single wall carbon nanotube ropes [2], and "shell sliding," in which the outer shell of a MWCNT is displaced relative to the inner shell adjacent to it [3, demonstration of a nanobearing].





1.Strength and breaking mechanism of multi-walled carbon nanotubes under tensile load. M-F Yu, O. Lourie, M. J. Dyer, K. Moloni, T. F. Kelly, and R. S. Ruoff, *Science*, **287**, 637 (2000). **2. Tensile loading of ropes of single wall carbon nanotubes and their mechanical properties**. M. F. Yu, B. S. Files, S. Arepalli, and R. S. Ruoff *Phys. Rev. Lett.*, **84**, 5552 (2000. **3. Controlled sliding and pullout of nested shells in individual multi-walled carbon nanotubes.** M. F. Yu, B. I. Yakobson, and R. S. Ruoff, *J. Phys. Chem. B*, **104**, 8764(2000). **4. Investigation of the radial deformability of individual carbon nanotubes under controlled indentation force.** M. F. Yu, T. Kowalewski, and R. S. Ruoff, *Phys. Rev. Lett.*, **85**, 1456 (2000). **5. Structural analysis of collapsed, and twisted and collapsed, multiwalled carbon nanotubes by atomic force microscopy.** M. F. Yu, T. Kowalewski, and R. S. Ruoff, *Phys. Rev. Lett.*, **86**(1), 88 (2001).

II. New methods have been developed for calibrating the forces of tapping mode atomic force microscopy, and of exploiting off resonance imaging as a means of studying the detailed geometry of carbon nanotubes on surfaces. For example, we have studied the response of MWCNTs to indentation force, and find that they can withstand local pressure of ~20 GPa (200 kbar) without damage [4]. The left figure shows a sequence of 4 images (of a MWCNT having a hair-pin shape on a Si wafer surface patterned with trenches) with increasing applied indentation force (clockwise, starting upper left), then returning (lower right) to very small imaging force—the MWCNT has survived ~20GPa local applied stress! These new methods have also been used to image partially, and also fully collapsed, MWCNTs (the latter are referred to as 'nanotube ribbons') [5]. The right figure shows a MWCNT ribbon for which we can determine the number of nested layers and from the observed structure, model the mechanics of collapse. An interior section ~1 um long is completely collapsed, extending from just above the symbol "(d)" to the arrow on the lower right. Notice that this ribbon section drops down into the trench it crosses, showing the greater compliance of ribbons vs cylindrical or near-cylindrical tubes.