

Abstract

Carbon nanotubes display unique and exciting new electronic and mechanical properties. Applications exist in a wide variety of fields because of their remarkable properties. To measure the shear properties this project required a modification of an Atomic Force Microscope. The method uses a sinusoidal laterally vibrating tip to produce a shearing effect as the tip is rastered over the substrate (graphite) and sample (carbon nanotube). The amplitude of the lateral oscillations gives a qualitative measurement for the stiffness of the tip's interaction by comparing the response of the substrate and sample. The substrate and sample were placed on a rotating stage to obtain a sequence of amplitude images of a nanotube in various orientations. The purpose was to compare the shear amplitude of the tip when it was in contact with the nanotube to the shear amplitude of the graphite for various orientations of the nanotube. The amplitude of the oscillations was about the same on the graphite as compared to a nanotube whose orientation was parallel to the scan direction, while the amplitude was much lower on a tube whose orientation was perpendicular to the scan direction.

Motivation

There is a wide array of potential applications for carbon nanotubes. Cabling for a space elevator, quantum wiring, bullet proof vests, SPM tips, torsional spring elements (as seen in Fig. 1) and hydrogen storage are all potential applications for this intriguing molecule, but before any of these can be developed we must have an intimate understanding of the properties of the nanotubes. The tensile strength and Young's Modulus have been studied extensively using different methods which produce data in fair agreement [1]. The shear modulus on the other hand has not been studied in depth and the data are not in agreement. Hence, the purpose of this project was to further the understanding of the shear properties of the material.

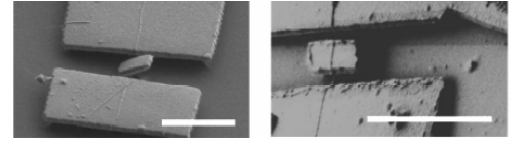


Figure 1 – A paddle made using a multiwalled carbon nanotube as the torsional spring element. The white bar represents 1 μ m [2].

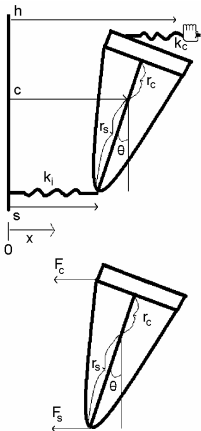


Figure 2 – Sketch and free-body diagram of the tip in equilibrium

The AFM's tip is scanned over the surface of the sample in contact mode, while being modulated by a sinusoidal function parallel to the scan direction. The tip's lateral oscillation across the substrate and sample, at a constant frequency, produces a shear stress on the material in contact with the tip, which is proportional to the rotation of the tip (as seen in upper part of Fig. 2). The shear force also produces a strain on the material, which is inversely proportional to the shear modulus. The greater the material's shear modulus the less it will strain and the larger the force that will be applied at the tip, resulting in higher twisting. The twisting of the tip causes the laser, which is reflected off the back of the tip, to change position on the position sensitive detector (PSD), which records the data from the C-D signal of the PSD (as seen in Fig. 3). In this manner topography and amplitude changes in lateral vibrations of the AFM's tip are measured simultaneously by two independent variables. A sequence of images was produced by taking an image as described above, and then changing the orientation of the tubes and graphite by rotating the rotatable stage, relocating the same tube and imaging it again in the new orientation.

Method

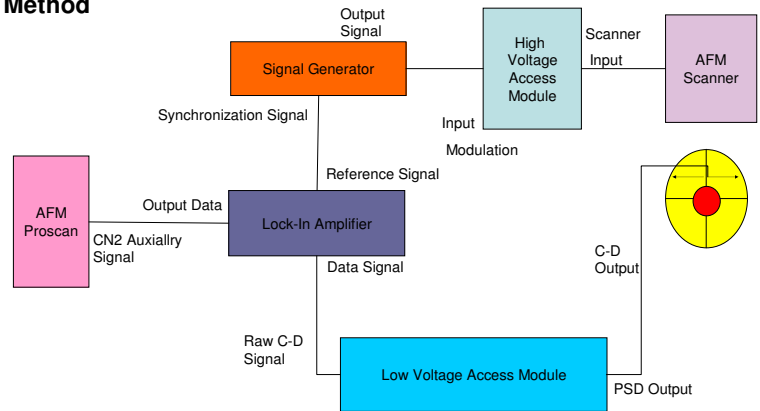


Figure 3 – Schematic of the electronic setup for the project

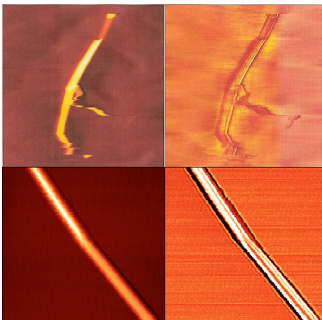
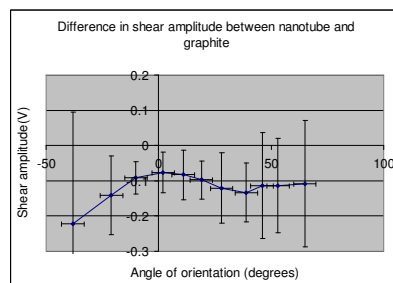


Figure 4 – Two pairs of images taken simultaneously. On the left are topography images where brightness represents height. On the right are shear amplitude images where brightness depicts stiffer interaction. The top pair of images is taken with a driving frequency of 6.6 kHz while the bottom's is 4.8 kHz. The lower shear amplitude image has a constant signal on the graphite as well as edge artifacts. Parameters such as the driving frequency were optimized using criteria of reproducibility and constant background signal, as well as minimization of artifacts associated with steps on the graphite.

Data



Graph 1 – A graph of the difference in response between the nanotube and the graphite as a function of the angle of the nanotube with respect to the scan direction (perpendicular to the long axis of the cantilever).

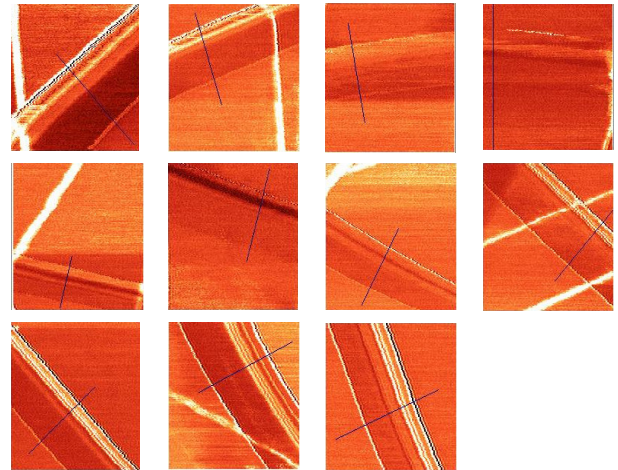


Figure 5 – A sequence of shear amplitude images in which each successive image is the same nanotube rotated ten degrees. The blue lines represent the cross-section across which a measurement was taken.

Conclusions

- Tubes that lie parallel to the long axis of the cantilever have less shear amplitude than the graphite. Tubes that lie perpendicular to the long axis of the cantilever display little difference from the graphite in the shear amplitude image; this implies that the shear modulus of carbon nanotubes is comparable to the shear modulus of graphite.
- Steps that occur in graphite produce almost no topography difference, but are very noticeable in the shear amplitude images. The steps appear as solid bright lines, and can be seen in the shear amplitude images even when covered by a tube.
- Edge artifacts (as seen in Fig. 5) can change contrast and thickness with different orientations, but remain constant within each image of the nanotube.
- Graph 1 appears to be roughly symmetric around the zero-degree orientation.
- An oscillation frequency of 2.7 kHz produced the most reproducible, scan-independent, and measurable response.

References

1. J.P. Salveat, G.A.D. Briggs, J.M. Bonard, R.R. Bacsa, A.J. Kulik, T. Stockli, N.A. Burnham & L. Forro; *Elastic and Shear Modulus of Single-Walled Carbon Nanotubes Ropes*. *Physical Review Letters* **82**, 944 (1999)
2. <http://www.physics.unc.edu/~falvo/papers/2003WIlliamsPaddleFabAPL2003.pdf>