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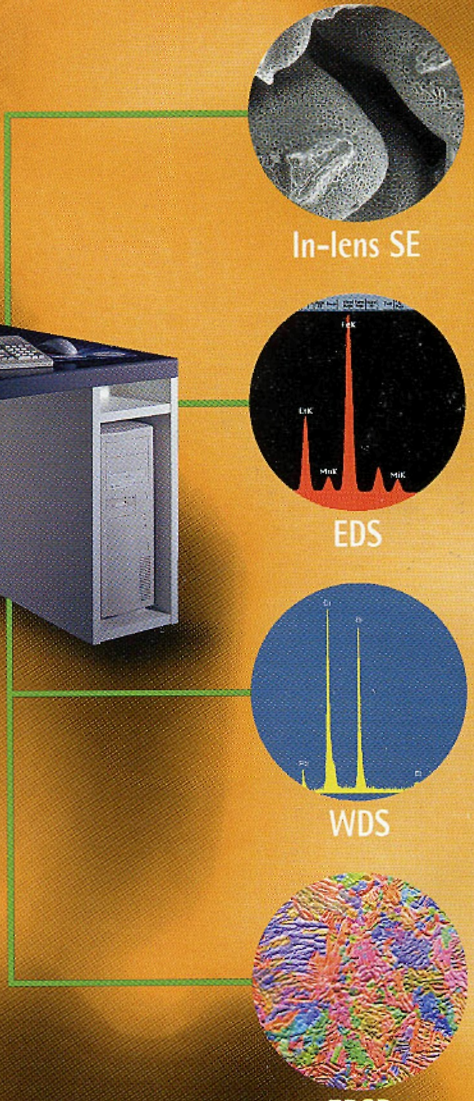

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Nanostructures Require Nanomeasurements

Stephen W. Carmichael[1], Mayo Clinic

Nanofabrication is upon us. But engineers require measurements of physical properties of their materials in order to use them appropriately. Because the size of the object is in the nanometer scale, tiny measuring devices are required. Furthermore, there is the problem of reading these tiny devices. Zhong Lin Wang, Philippe Poncharal, and Walter de Heer at Georgia Tech have solved this problem by using the transmission electron microscope (TEM) to read off the measurements[2].

A special device was designed to fit inside the TEM, allowing for simultaneous visualization and manipulation of a nanostructure. The nanostructure that Wang *et al.* used was the carbon nanotube which could be clearly visualized by the TEM and has a well-defined structure. Specifically, they used multiwalled nanotubes with diameters of 5 to 50 nm and lengths of 1 to 20 μm. The device they designed for *in situ* microscopy was a modified specimen holder that allowed carbon nanotubes to be mounted in a conducting medium and positioned across from a counter electrode, which was a droplet of mercury or gold/ platinum balls. A specific nanotube could be visualized and an electric potential was applied between the nanotube and the counter electrode to carry out a variety of measurements. Thereby measurements could be done on a specific nanotube whose microstructure could be determined by transmission electron imaging and diffraction. Thus, the atomic-scale structure of the object whose properties are being measured is known.

The TEM they used had a relatively low vacuum at the specimen stage so that mercury could exist in the liquid state. The 100 kV electron beam did not damage the carbon structure, so extensive observations could be carried out on a single nanotube. Also, a large angular tilting range allowed precise measurements of the length of the nanotube which was necessary for determining the precision of the measurement.

Wang *et al.* could examine mechanical strength of a nanotube by applying an external voltage that results in an electrostatic force that deflects the nanotube. The nanotube could be bent to 90° and still recover its original shape. Applying negative and positive voltages gave rise to cyclic loading of the nanotube and allowed a direct measurement of its elastic limit. Alternatively, resonance could be induced with an oscillating voltage and the frequency could be accurately measured. This allowed Wang *et al.* to calculate the bending modulus of the nanotube, which was as strong as a diamond!

Electrical conductance of a single carbon nanotube was also measured with the *in situ* microscopy device. Interestingly, quantum conductance was observed, which means that electrons pass along the nanotube without generating heat. This could be important for nanoelectronics. Wang *et al.* also studied the electrical field-induced field emission characteristics of a single nanotube. The emission of electrons at an applied voltage could be visualized as a dark contrast near the tips of the nanotube. A detailed analysis of this phenomenon is underway using electron holography.

Perhaps the most fascinating experiment reported by Wang *et al.* resulted in their discovery of a "nanobalance," the most sensitive and smallest balance ever made. Analogous to a spring balance, the mass of an object at the end of a spring can be determined if the vibration frequency is measured and the spring constant is calibrated. They attached a small particle to the end of a nanotube and observed that the resonance frequency dropped about 40%. The mass of the particle was calculated from the frequency to be 22 ± 6 femtograms (femto = 10^{-15}, one millionth of a nano!). It was suggested that this nanobalance could be used to weigh single virus particles, or other biological molecules.

These fascinating experiments point to a way of using TEM to making quantitative measurements at the nanometer scale. The key appears to be in getting a close enough look to read the instruments. This is a new application of the TEM and a critical step in nanotechnology. ■

1. The author gratefully acknowledges Dr. Z.L. Wang for reviewing this article.

2. Wang, Z.I., P. Ponchard, and W.A. de Heer, Nanomeasurements in transmission electronmicroscopy, Microsc. Microanal. 6:224-230, 2000.

INDEX OF ARTICLES