Ability to Control Configuration and Length of Nanotubes Demonstrated

The ability to control the structure and arrangement of carbon nanotubes (CNTs) is a prerequisite to realizing many nanoscale applications. Researchers from Rensselaer Polytechnic Institute (RPI) in Troy, N.Y., and from Tsinghua University in Beijing have discovered methods for arranging CNTs into specific configurations that exhibit distinct electrical and mechanical properties. These techniques have recently been reported in *Science* and *Nature*.

As reported in the May 3 issue of *Science*, teams led by P.M. Ajayan at RPI and H.W. Zhu at Beijing University have developed an optimized catalytic chemical vapor deposition (CVD) technique that can be used to synthesize long, continuous strands of single-walled nanotubes (SWNTs). The researchers introduced an *n*-hexane solution composed of ferrocene and thiophene into a vertical reactor heated to the pyrolysis temperature and flowed hydrogen as the carrier gas. The usual CVD processes that are used to create SWNTs typically result in nanotube bundles that are tens of micrometers in length. In the researchers' technique, the reaction temperature and hydrogen flow rates were optimized to create a continuous process that yielded macroscopic strands of SWNTs up to several centimeters in length. The use of *n*-hexane, as opposed to other hydrocarbons, and a hydrogen carrier gas was crucial to achieving high SWNT yields and large self-assembled strands. Resistivity measurements on as-grown SWNT strands with lengths ranging from 10 cm to 20 cm and diameters ranging from 50 μm to 0.5 mm were low enough to indicate that macroscopic lengths of conducting paths or nanotubes existed in the strands. Estimates of

SWNTs Ignite on Exposure to a Camera Flash

In an alliance between RPI, IPCYT in Mexico, the University of Sussex in England, and Université Louis Pasteur in France, Ajayan, M. Terrones, and co-workers accidentally discovered that SWNTs ignite when exposed to a photographic flash from a camera. As reported in the April 26 issue of *Science*, an ignition effect occurs in SWNTs prepared by carbon arc, laser ablation, or CVD upon exposure to a camera flash within several centimeters of the CNT. The researchers found that the average light power necessary for SWNT ignition was ~100 mW/cm^2 for a sample density of 0.2 g/cm^3. When local increases in temperature caused by a flash initiate oxidation of the carbon, ignition and burning occur during an exothermic reaction. CNTs exposed to photographic flashes in air underwent large structural reconstruction even if burning did not occur. Electron microscopy studies of flashed SWNTs showed that the remaining unburned carbonaceous material was transformed into single-layered structures with many conical tips. Under vacuum or in Ar, reconstruction resulted in partially graphitized filaments and disordered graphene, whereas in He, large amounts of nanohorn material was formed. While temperatures of 600–700°C are necessary to oxidize and cause ignition of CNTs, even higher temperatures (~1500°C) are required for the extensive reconstruction seen in these experiments.

STEFFEN K. KALDOR

the Young's modulus of centimeter-long CNT strands, which were obtained from tensile tests, ranged from 49 GPa to 77 GPa, or approximately five times the moduli previously reported for oriented SWNT fibers and ribbons.

In the April 4 issue of *Nature*, B.Q. Wei, Ajayan, and co-workers at RPI and Motorola Physical Science Research Laboratories in Tempe, Ariz., describe a technique for arranging CNTs into well-defined configurations. The researchers stimulated CVD nanotube growth by exposing a Si/SiO_2 substrate to a xylene/ferrocene [C_8H_{10}/$Fe(C_5H_5)_2$] vapor mixture at 800°C. Multiwalled nanotubes (MWNTs), aligned normal to the substrate surface, were grown in blocks of micrometer-sized, densely packed cylindrical pillars whose heights were controlled to within 1–2 µm. The researchers used this technique, which can grow CNTs in multiple directions simultaneously, to realize periodic arrays of vertically *and* horizontally aligned CNTs grown on repeating patterns of SiO_2.

New techniques for manipulating the structure of CNTs will allow for the tuning of mechanical and electrical properties of nanostructures and will help researchers realize new nanoscale applications. Long continuous strands of SWNTs may eventually serve as highly conductive microcables, and well-ordered nanotube patterns may prove useful in the manufacture of integrated systems and electromechanical devices, according to the research teams.

STEFFEN K. KALDOR

Beryllium Compound Refractive Lenses Focus 6.5-keV X-Rays

X-ray collimation and focusing is a topic well discussed in the scientific community. Optical refractive methods have been considered ineffective for x-ray wavelengths, and efforts have focused on the utilization of Fresnel diffraction, Bragg reflection, or specular reflection for x-ray focusing and collimation. However, the use of compound refractive lenses (CRLs) has become the subject of much scientific research, as the x-ray sources have evolved to brighter and more collimated characteristics. The group of H.R. Beguiristain from Adelphi Technology and R.H. Pantell from Stanford University has demonstrated the use of large-aperture compound beryllium lenses to achieve gains of 1.5 and focal lengths of 93 cm at 6.5 keV. The compound refractive lens was made of 160 biconcave unit lenses, each with a radius of curvature of 1.9 mm. The use of beryllium extends the range of operation of compound refractive lenses, improving transmission, aperture size, and gain.

As reported in the May 1 issue of *Optics Letters*, Be lenses were constructed with a maximum thickness of 0.76 mm and a minimum thickness of 40 µm and with a mechanical aperture (diameter) of 2.29 mm. Measurements of lens performance were performed at Stanford Synchrotron Radiation Laboratory. The line was equipped with a double-crystal monochromator capable of delivering x-rays from 2.4 keV to 30 keV with 5×10^{-4} resolution. The nominally expected source size for this beam is 0.44 mm × 1.7 mm. The x-ray beam size upstream of the CRL was reduced to 1 mm × 1 mm by the use of entrance slits. The dimensions of the exit slits were adjusted to below 25 µm and then translated in the *x* and *y* directions across the focused x-ray beam. The x-ray ionization chamber was fixed downstream from the exit slit and measured the total x-ray power passing through it.

The vertical and horizontal scanning widths were measured at various positions along the direction of beam propagation. The beam size profile as a function of the distance along the propagation axis was plotted and the beam waist (minimum beam spot size) was determined to be 42 µm, full width at half maximum