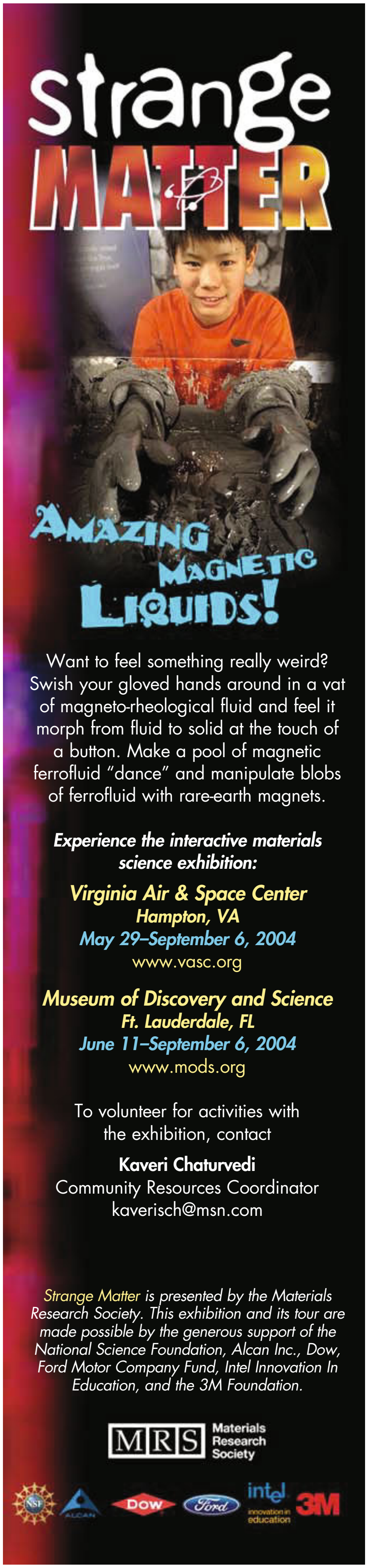

of the proper unset strand frees the right foot from the middle foothold, although it is still tethered to the left foot (state 2, Figure 1c). The addition of a set strand results in the right foot attaching to the right foothold (state 3, Figure 1d). The flexible linkers must be long enough to extend from the left to the right foothold, a gap of about 2 nm. Similar unset and set steps remove the left foot from the left foothold (state 4, Figure 1e) and attach it to the middle foothold (state 5, Figure 1f). The researchers verified each of the states by illuminating the structures with UV light, which resulted in covalent bonds between single-stranded DNA (due to the presence of the psoralen), and then performing polyacrylamide-gel electrophoresis.

Sherman and Seeman said that their device has precise bidirectional control and that a longer gait can be achieved with longer footpaths, which might also accommodate multiple, independently addressable bipeds and multipeds. They said that rotational motion can be achieved with circular footpaths. The researchers envision applications such as the transportation of loads and the winding or threading of polymers. In addition, Sherman and Seeman believe that "algorithmically generated set strands could drive a device on a 2D footpath so that the positions of the feet could represent the state of a DNA-computational machine."

STEVEN TROHALAKI

Bi_2O_3-Coated Zinc Oxide Nanoparticles Yield High-Quality Ceramics

Polycrystalline ceramic zinc oxide (ZnO) varistors, which include an intergranular bismuth-rich phase, are known to show excellent nonlinear current–voltage properties. These materials are typically made by sintering physically mixed precursors and thus often have poor microstructural uniformity and porosity. F. Yuan of the Chinese Academy of Sciences and the Korean Research Institute of Chemical Technology and H. Ryu, also of the Korean Research Institute, have found that sintering ZnO nanoparticles that have been uniformly coated with Bi_2O_3 results in ZnO ceramic varistors with perfect and homogenous ZnO grains, each of which is completely surrounded by a uniform Bi_2O_3 layer.

As described in the April issue of the *Journal of the American Ceramic Society* (p. 736), Yuan and Ryu used predesigned nanoparticles as precursors to prepare the ceramic varistors. The researchers precipitated a $Bi(NO_3)_3$ solution onto a slurry of basic carbonate-of-zinc and after calcination obtained ~30–50-nm-sized ZnO nanoparticles with homogenous Bi_2O_3 coatings. These particles were then sintered at 1150°C for 1 h to obtain the ZnO ceramics.

Yuan said, "The major advantage of this process is that ZnO nanoparticles coated with Bi_2O_3 can give a uniform liquid phase environment for every ZnO particle." The ceramics prepared from these precursors exhibited uniform grain size ranging from 3–5 μm for samples with 1 wt% Bi_2O_3 to 8–10 μm for samples with 3 wt% or 5 wt% Bi_2O_3.

The eutectic temperature for the $ZnO–Bi_2O_3$ system is ~740°C; above this temperature, a liquid phase is formed. In using the preformed, coated particles, each ZnO particle is in a homogenous medium, thus the ZnO grains grow homogeneously and perfectly. The researchers observed that above 3 wt% of Bi_2O_3 there is a continuous skeleton of the bismuth-rich phase completely surrounding the perfectly formed ZnO grains. They also determined that the ZnO grains do not grow once the bismuth-rich phase has formed a continuous grain boundary surrounding the ZnO grains. The lack of porosity and good grain condition as well as the excellent grain-boundary properties are expected to have favorable effects on the varistor properties under high current.

SARBAJIT BANERJEE

Bandgap of Semiconducting Nanotubes Shrinks in High Magnetic Fields

A team of researchers headed by Richard Smalley at Rice University has discovered that the bandgap of semiconducting single-walled carbon nanotubes (SWNTs) shrinks monotonically as a function of magnetic flux densities up to 45 T (Figure 1). The findings confirm quantum mechanical theories offered more than four decades ago by Aharonov and Bohm. According to lead researcher Junichiro Kono, an assistant professor of electrical and computer engineering at Rice, the SWNTs will likely become metals at >100 T.

A magnetic flux passing through a mesoscopic ring structure modifies the quantum states and the dynamics of electrons in the ring. Quantum-interference effects, manifested, for example, as oscillations in magnetoresistance, occur when the phase coherence length exceeds the circumference. However, a magnetic flux passing through SWNTs interacts with them in a different fashion than would occur with a mesoscopic ring, because the SWNTs have a periodic lattice potential along the circumference of the nanotube.

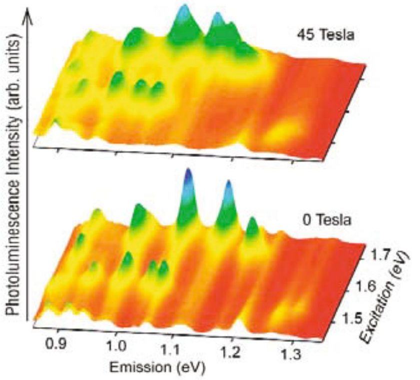

Figure 1. The peaks represent the amount of light emitted by semiconducting carbon nanotubes through interband photoluminescence. The bottom graph depicts light-emission activity in the absence of a magnetic field. The top graph shows a significant shift of light emission peaks to lower energies taken from nanotubes inside a 45-T field. (Figure courtesy of Sasa Zaric, Rice University.)

As reported in the May 21 issue of *Science* (p. 1129), the researchers placed solutions of nanotubes inside a chamber containing very strong magnetic fields. Lasers illuminated the samples, and conclusions were drawn based upon analysis of the light absorbed and emitted by the samples during polarization-dependent magneto-absorption spectroscopy.

Kono said, "Our data show…that the so-called Aharonov-Bohm phase can directly affect the band structure of a solid. The Aharonov-Bohm effect has been observed in other physical systems, but this is the first case where the effect interferes with another fundamental solid-state theorem, that is, the Bloch theorem. This arises from the fact that nanotubes are crystals with well-defined lattice periodicity. I wouldn't be surprised to see a corresponding effect in other tubular crystals like boron nitride nanotubes."

According to the researchers, the bandgap behavior of the nanotubes in a strong magnetic field derives from their quantum properties. Because of the material's tubular, crystalline structure, electrons are limited to moving around the surface of the tube rather than in the hollow center.

Kono said that this discovery may lead to experiments on one-dimensional magnetoexcitons, quantum pairings that are interesting to researchers studying quantum computing, nonlinear optics, and quantum optics.

α-SiAlON Ceramics with High Transparency Obtained After Lu_2O_3 Addition

The most widely studied SiAlON ceramics, for which the two major phases are α and β, are those stabilized with Y_2O_3. Oxide additions help to stabilize the α phase of the Si_3N_4-based solution by substituting some of the silicon and nitrogen in the Si_3N_4 lattice. Further addition of a stabilizing element, usually a rare earth, equilibrates the valence difference of the α phase. The smaller the size of the ion added, the larger the temperature