Soluble CdS and CdSe Nanorods Synthesized

Some potential practical applications of semiconductor nanorods—for example, optoelectronic light-emitting diodes for nanowires—require the fabrication of nanorods with precisely specified aspect ratios (length / diameter). However, no method has been reported so far for the synthesis of colloidal semiconductor rods with a narrow distribution of aspect ratios. Researchers at National Taiwan Normal University have synthesized water-soluble crystalline nanorods of CdS and CdSe by using micellar templating in which the shapes of the templates are controlled by the addition of cyclohexane to a micelle suspension.

As reported in the July 2000 issue of *Chemistry of Materials*, the micelle suspensions were formed by the dissolution of CTAB ($CH_3(CH_2)_{15}N(CH_3)_3Br$) in deionized water. Metal and chalcogenide precursors (CdC_{l2}, Na_2S, or Na_2Se) were then added to form two precursor suspensions. The researchers added various amounts of cyclohexane (0–0.1% by volume) to these suspensions, followed by sonication. They slowly added the chalcogenide suspensions to the metal suspensions, and the resulting mixture was sonicated and centrifuged to separate out the suspended product.

Transmission electron micrographs showed that the reaction products consist of crystalline nanorods as well as spherical and irregularly shaped nanocrystalline materials. The TEM images revealed CdSe and CdS samples with the mean aspect ratios of ~6. A high-resolution TEM image of the CdS nanorods showed an average diameter of ~9 nm. Although further work is needed, the results suggest that rod aspect ratio increases with increasing amounts of added cyclohexane. HRTEM images indicated that CdS and CdSe nanocrystals have wurtzite and zinc-blende structures, respectively. Selected-area dispersive x-ray studies of the CdS nanocrystals showed a Cd:S ratio of 1:1.

The addition of cyclohexane is thought to affect the shapes of the micelles and, therefore, the nanocrystals that form inside them. While the exact role of the hydrocarbon is not known, according to the researchers, one possibility is that it induces a micelle-shape transition. Such morphological changes have been previously observed in CTAB micelle suspensions with other hydrocarbons. Another possibility, according to the researchers, is that bilayer vesicles form in the suspension under intense sonication, and "cyclohexane molecules incorporate into the bilayers and subsequently induce the morphologic changes of the bilayer vesicles."

GREG KHITROV

Review Articles

The April 21 issue of *Science* features the following review articles on Correlated Electron Systems: Y. Tokura and N. Nagaosa, "Orbital Physics in Transition-Metal Oxides"; J. Orenstein and A.J. Millis, "Advances in the Physics of High-Temperature Superconductivity"; S. Sachdev, "Quantum Criticality: Competing Ground States in Low Dimensions"; and P.W. Anderson, "Sources of Quantum Protection in High-T_c Superconductivity."

The July issue of *Reviews of Modern Physics* contains the following review articles: J.J. Rehr and R.C. Albers, "Theoretical Approaches to X-ray Absorption Fine Structure"; H. Feldmeier and J. Schnack, "Molecular Dynamics for Fermions"; S. Hofmann and G. Münzenberg, "The Discovery of the Heaviest Elements"; J.E. Sonier, J.H. Brewer, and R.F. Kiefl, "muSR Studies of the Vortex State in Type II Superconductors"; J.-L. Viovy, "Electrophoresis of DNA and Other Polyelectrolytes: Physical Mechanisms."

Magnetoresistance and Differential Conductance in Multiwalled Carbon Nanotubes

In an attempt to determine whether carbon nanotubes conduct current ballistically or diffusively, researchers from Chonbuk National University, the Korean Research Institute of Standards and Science, and the Electronics and Telecommunication Research Institute have measured magnetoresistance and differential conductance (dI / dV) as a function of a magnetic field applied perpendicular to the tube axis. As reported in the June 15 issue of *Physical Review B*, these measurements provided evidence that the source of the negative magnetoresistance and differential conduction is the change in the density of states (DOS) near the Fermi level as a function of the applied magnetic field.

Two multiwalled carbon nanotube samples synthesized by an arc-discharge method were prepared on a SiO_2–Si substrate. The researchers patterned electrical leads using e-beam lithography. They then deposited 20 nm of Ti and 50 nm of Au onto the contacts by using a thermal evaporation technique. They then annealed the sample systems at temperatures between 600°C and 800°C for 30 s to produce ohmic contacts.

Two samples with different voltage-probe separation distances and contact resistances underwent changes in magnetoresistance as a function of the applied field. These changes became more pronounced as the experimental temperature decreased. Experimental temperatures were in the vicinity of 35 K. Two regions of interest exist: the point of maximum magnetoresistance and the point of minimum magnetoresistance. The maximum point was temperature-dependent, that is, magnetoresistance increased as the temperature decreased. Magnetoresistance at the minimum point was temperature-invariant.

At the maximum point, differential conductance is highly nonlinear. A plot of dI / dV versus voltage revealed the depletion of states near the Fermi level. Conductance is therefore concluded to be a function of the DOS near the Fermi level. Magnetoresistance is found to be a function of both applied current and ambient temperature.

At the minimum point (applied field was 7 T for one sample, 4 T for the other), dI / dV was constant, and therefore the nanotubes exhibited ohmic behavior. Magnetoresistance was no longer a function of applied current. The measured conductance approaches the theoretical value (of $2G_0 = 4e^2 / h$), indicating conduction primarily through only the outer graphene wall and thus is not a function of the electronic DOS.

The researchers concluded that low-temperature conduction of carbon nanotubes is governed by "magnetic-field-induced band transport, rather than the quantum interference effect."

JUNE LAU

Carbon Nanotube Electric Charge Divides into Charge "Islands"

Physicists Sander Tans and Cees Dekker of the Quantum Transport section at Delft University of Technology have determined that the electrical charge in a semiconductive carbon nanotube is not evenly distributed, but rather is divided into separate charge "islands."

Dekker said, "This insight is important if conductive nanotubes are eventually to be used in electric circuits. We had already made a transistor from a single nanotube and now wanted to know how the charge changes over the length of the tube. Such a charge profile could help us understand how the nanotube transistor works."

As they reported in the April 20 issue of *Nature*, Tans and Dekker sent an electrical

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charge through the tube, causing electrons to be transported through it. By measuring the charge field at several points on the tube with an atomic force microscope, they viewed local charge differences. Dekker said, "The charge seems to be concentrated in small islands at intervals of approximately 40 nm. We had not expected this. The electrons apparently jump from one point to another, and this provides the conductive capacities of the nanotube."

Crystalline Selenium Nanowires Produced

The fabrication and properties of nanostructures, including dots and wire, has elicited much interest. A method has been introduced in the July 2000 issue of *Chemistry of Materials* that allows the fabrication of selenium nanowires in one chemical reaction in aqueous solution at room temperature. This technique was developed through a collaborative effort by researchers at the University of New Mexico, Sandia National Laboratories, and the Universidade Nova de Lisboa.

The first step in the nanowire fabrication was the reduction of the selenate ion (SeO_4^{2-}) to elemental selenium (Se^0) by the enzyme cytochrome c_3, with sodium dithionite ($Na_2S_2O_4$) serving as the electron donor. Cytochrome c_3, which is well known for its ability to catalyze the reduction of metals, was extracted from the sulfate-reducing bacteria *Desulfovibrio vulgaris* (strain Hindenborough). In the second step of the fabrication process, the colorless selenium solution was allowed to stand until it turned red (1 week), indicating the precipitation of red selenium.

Transmission electron microscope characterization of the product showed the presence of nanowires roughly 60 nm in diameter and 1 μm long, consisting of a single strand of stacked nanoparticles with visible grain boundaries between them. Larger diameter wires with several nanoparticles in parallel were also present, along with isolated spherical nanoparticles roughly 50 nm in diameter. Electron-diffraction studies showed that the nanowires were crystalline, with a monoclinic structure that is consistent with red selenium. The wires were stored in water solution for at least 10 weeks with no degradation; the aging resulted in the formation of longer but not thicker wires.

The mechanism of selenium nanoparticle assembly into nanowires is not known, but the researchers speculate that "the stacking of nanocrystals in the same [crystallographic] direction provides an energetically favorable link between them." Similar stacking was previously observed for silver nanocrystals.

GREG KHITROV

Magnetic Actuation Folds Microparts into 3D Structures

Researchers at the University of Illinois—Urbana-Champaign have utilized a magnetic field to assemble large arrays of three-dimensional microstructures, ~100 μm on a side. To fabricate arrays of 3D structures, individual components are first cast in place on sacrificial layers using planar deposition. A small amount of magnetic material is electroplated onto each of the parts, which are then freed from the substrate by a highly selective etchant consisting of 49% hydrofluoric acid. The etchant attacks the oxide sacrificial layer but not the structure materials, which are made of polysilicon. When a magnetic field is

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