Nitrogen in Semiconductor Alloy Splits Conduction Band in Two, Reducing the Bandgap

In a search to increase the efficiency of solar cells, researchers have incorporated small amounts of nitrogen into the semiconductor alloy gallium indium arsenide. Usually, the incorporation of smaller atoms such as nitrogen into a semiconductor alloy causes the material's bandgap to increase; however, the addition of even a little nitrogen to gallium indium arsenide decreases its bandgap dramatically. Researchers at Lawrence Berkeley National Laboratory (LBNL) and the National Renewable Energy Laboratory (NREL) have found that nitrogen forms a narrow energy band in gallium indium arsenide that splits the alloy's conduction band in two. The subbands push each other apart, and the lower subband reduces the fundamental bandgap.

Wladek Walukiewica of LBNL said that data from other semiconductors with low concentrations of nitrogen had indicated that nitrogen produces a localized, narrow band of its own. Walukiewica said that while the bandgap to the conduction band's lower part was reduced to 1 eV, "there is also an upper conduction band, and we needed to find it and characterize its behavior to prove our model."

According to their article published in the February 8 issue of *Physical Review Letters*, on a substrate of gallium arsenide the researchers grew samples of gallium indium arsenide with varying small concentrations of nitrogen. The samples, only 200 μm^2 and less than 5 μm thick, were examined with modulated beams of light as the samples were squeezed in a diamond anvil cell.

The scientists reported that the signature of two conduction bands was revealed in photomodulated transmission measurements using different colors of modulated light. In agreement with Walukiewicz's model, the conduction bands initially moved closer and then grew farther apart as the pressure was gradually increased. This repulsive "anticrossing," a well-known quantum mechanical effect, confirmed the model.

Walukiewicz said, "The flat curvature of the lower band is not good news for electron mobility." He said that as charge carriers, the electrons are short-lived and tend to recombine with holes before they have traveled far enough to contribute to the solar cell's output of electric current.

"We are now working to see if the split-band structure affects carrier mobility in a basic way, or if there are approaches that might improve the situation," he said.

Shape and Microstructure of Graphite Flakes Affects Cracking and Chipping in Cast Irons

Engineers from The Pennsylvania State University have shown that the shape of graphite flakes as well as the microstructure in cast irons influence the amount of cracking and chipping that occurs during the machining process used to make gears, engine blocks, and other finished parts. According to a paper presented at the American Foundryman's Society meeting in St. Louis in March, the group looked at commercial grades of gray and ductile cast iron, using slow speed machining as well as a high-speed quick-stop device. They used a high magnification video camera

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system to record the process and then examined the machined samples with optical and scanning electron microscopes.

Magnified 50 times in the research videotapes, cracks were seen along the graphite flakes and severe deformation in the surrounding matrix structure. The longer the graphite flakes, the longer the fracture distance ahead of and below the cutting tool.

The research also revealed that fine free graphite exists at the tool/chip interface of all gray irons and performs an important lubrication role. The graphite at the interface forms a thin solid film that separates the tool from the work and reduces strain and friction. The result is lower tool/sample interface temperatures and enhanced machinability.

The researchers also found that the type of matrix or fine microstructure in which the graphite was embedded played a role in machinability. They examined typical cast iron microstructures, including ferrite, ferrite/pearlite, and fully pearlite, and found that the higher the amount of ferrite, the easier it is to machine.

Gray irons have different machining characteristics than ductile irons and leaded steels. Ductile irons are more plastic and form longer chips than gray irons. Leaded steels show a much higher ductility than ductile irons, longer deformation distances, and the formation of continuous chips during machining.

Robert C. Voigt, professor of industrial engineering at Penn State, said that the researchers are currently forming a consortium of companies to further examine the role of graphite and structure on cast iron machinability. Their goal is a consistently machinable cast iron that will provide better performance than it currently does when machined rapidly by automated machining cells.

Actuators Developed from Carbon Nanotubes

A multinational team of scientists from Germany, the United States, Australia, and Italy, has fabricated conducting actuators by using single-walled nanotube (SWNT) sheets. As seen in the figure, strips of "bucky paper" are placed on both sides of a scotch tape. Electrochemically, one side is charged negatively (with positive sodium counterions), and the other positively (with negative chloride counterions). Both

Review Articles

The March 12, 1999 issue of *Science* features the following review articles on single molecules: W.E. Moerner and M. Orrit, "Illuminating Single Molecules in Condensed Matter"; S. Weiss, "Fluorescence Spectroscopy of Single Biomolecules"; J.K. Gimzewski and C. Joachim, "Nanoscale Science of Single Molecules Using Local Probes"; and A.D. Mehta, M. Rief, J.A. Spudich, D.A. Smith, and R.J. Simmons, "Single-Molecule Biomechanics with Optical Methods."

The October 1999 issue of *Reviews of Modern Physics* will contain Nobel Lectures by Walter Kohn, "Electronic Structure of Matter—Wave Functions and Density Functionals" and John A. Pople, "Quantum Chemical Models." The issue will also contain materials-related review articles by G. Khitrova, H. M. Gibbs, F. Jahnke, M. Kira, and S. W. Koch, "Nonlinear Optics of Normal-Mode-Coupling Semiconductor Microcavities" and Pablo Jensen, "Growth of Nanostructures by Cluster Deposition."

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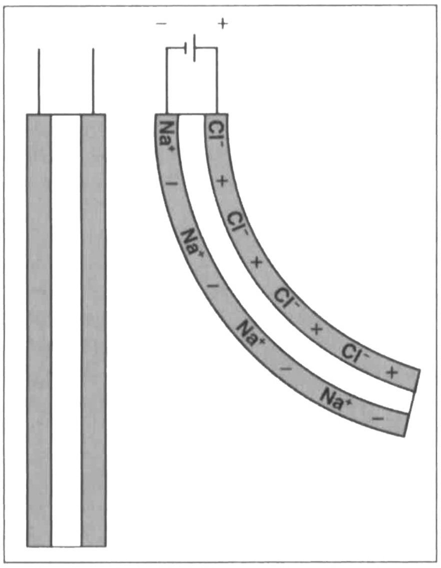

Carbon nanotube actuator.

sides expand (in neutral bucky paper, chemical bonding is optimized), but the positive side expands more than the negative, and the whole structure bends, like a human arm bends by contracting a muscle on one side and expanding its antagonist on the opposite side.

As reported in the May 21 issue of *Science*, the scientists created bucky paper by entangling ropes formed out of several hundred individual nanotubes. The scientists dipped a strip of bucky paper into salt water and electrochemically charged the material by changing the potential to +/- 1 V versus a standard electrode. This changed the length of a straight strip of bucky paper by about 0.04%. According to the researchers, while this seems to be a very small change, compared with other actuator materials (piezoelectric devices), it is fairly large, and the voltage needed is fairly small.

Hydrocarbon Identified as Molecular Source of Friction

Amontons' laws state that the frictional force needed to slide one body over another is proportional to the load that presses them together and is also independent of the areas of the surfaces. Physicists at The Johns Hopkins University have accounted for the notable endurance of Amontons' equations by identifying the molecular origins of static friction. As reported in the June 4 issue of *Science*, Mark Robbins, professor of physics at Johns Hopkins, said that hydrocarbon molecules are almost always present between two surfaces. Robbins and his colleagues propose that these molecules "adsorb on any surface exposed to air and can arrange to lock two contacting surfaces together."

Using molecular dynamics models, Robbins and his colleagues simulated the presence of "third body" hydrocarbons along the interface of a variety of contact surfaces. They discovered that varying the length of the molecular chain produced little change in the coefficient of friction. Increasing the number of hydrocarbon layers also had no real effect.

Robbins said, "Clearly our model doesn't have all the complexity of the real world—the roughness of real surfaces, the chemical properties of different materials, and actual molecules—but it does show how important these third bodies are."

Linear Defect Influences High Critical Currents in $YBa_2Cu_3O_{7-\delta}$ Thin Films

An international team of researchers has determined that edge and screw dislocations are operative in superconducting $YBa_2Cu_3O_{7-\delta}$ thin films. As reported in the June 3 issue of *Nature*, the team determined the as-grown dislocation density by etching 140-mm thick $YBa_2Cu_3O_{7-\delta}$ film in a 1% Br/ethanol solution. Because etching does not immediately remove the growth features on this type of film, the scientists were able to locate the position of the etch pits in respect to that of the growth spirals on the film through atomic force microscopy. Their results showed a double spiral with a single unit-cell step height. The researchers said that the etch pits at the spiral center point to screw dislocations and that the pits randomly distributed over the spiral are due to edge dislocations.

Both types of defects act as preferential etch sites and by changing the growth conditions scientists are able to tune the linear defect density. The number of linear defects appeared to be proportional to the growth island density.

The researchers from Vrije and Leiden Universities in The Netherlands, CNR in Italy, Johannes Gutenberg University in Germany, and the National University of Colombia have further determined that these natural linear defects are the main source of strong vortex pinning; that is, they are responsible for the high j_c observed in these films. By measuring the

Recently Announced CRADAs

Ames Laboratory (Ames, Iowa) and **Astronautics Corp. of America** (Milwaukee, Wisconsin) have signed a Cooperative Research and Development Agreement to develop a rotary prototype magnetic-refrigeration unit.

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superconducting current density as a function of temperature (between 4.2 and 80 K) and magnetic field (≤ 7 T), the researchers found the dislocation density to be proportional to B*, that is, the magnetic field up to which the critical current j_c (B) remains constant, before starting to decay. Up to B* all vortices are pinned, each by one linear defect. Above B*, essentially no defect is available and the remaining vortices are located at interstitial sites. These unpinned vortices are then responsible for the resulting decay in j_c.

Accordingly, the researchers report that "no correlation is found between the density of linear defects and the value of the critical current density...which shows that the critical current at low fields is solely determined by the pinning of single vortices along extended defects."

Use of Optical Tweezers Uncovers Micromechanical Properties of Dipolar Chains in Magnetorheological Suspensions

In order to understand how magnetorheological (MR) fluids behave at the microscopic level, professor Alice P. Gast and graduate student Eric M. Furst of the Chemical Engineering Department at Stanford University applied optical trapping techniques as they studied an MR suspension consisting of superparamagnetic particles dispersed in a nonmagnetic fluid. As reported in the May 17 issue of *Physical Review Letters*, Gast and Furst used polyvinyl microspheres to manipulate the particles in MR fluids. Because the presence of iron oxide disrupts the action of the optical tweezers, the researchers attached "tethers" consisting of nonmagnetic microspheres. Using two optical tweezers, they were able to grip the tether spheres and use them to pull apart individual chains of magnetized spheres while measuring the amount of force that was required.

The researchers found that it takes about four times the force to pull the chains apart than the simple models had predicted. The researchers suggest that the models, which treat the particles as simple point dipoles, do not consider that each particle generates its own local field, which acts to stiffen particles nearby.

They also found that, as they were pulling chains apart, extra spheres frequently popped into the chain. Such additions lowered the tension in the chain momentarily, and caused the chains to fail more gradually than previously predicted.

As Gast and Furst varied the strength of the magnetic field, they found that at very high field strengths, the chains form and cross-link to give the material a solid form. At low field strengths, the chains disintegrate. At intermediate strengths, the material becomes elastic and the researchers found that the chains can undergo a reorganization into mechanically stronger configurations, similar to work hardening in plastics.

As the individual chains joined together to form columns, the scientists found an increase in tensile strain of a short dipolar column as the dipole strength decreased.

Artificial Capsules (Polymersomes) Mimic Biological Cells

Bioengineers from the Institute for Medicine and Engineering (IME) at the University of Pennsylvania have designed an artificial capsule called a polymersome that imitates many of the qualities of natural cells. Daniel Hammer, professor of chemical engineering, said "The polymersomes are the same size as natural cells, but their outer membrane is much tougher than the phospholipid membrane of biological cells." He also said that the capsules are undetectable by the human immune system so they can be used to deliver drug therapies.

As reported in the May 14 issue of *Science*, the researchers produced the capsules from the diblock copolymer EO_{40}-EE_{37}. They dried the carbon-based polymer and an organic solvent on a wire, added water to the system, and applied electricity to the wire. Over time, as the polymer film lifted off the wire's surface, capsules formed.

According to Dennis Discher, assistant professor of mechanical, chemical, and bioengineering, the largest artificial cell made prior to these are 1 μm in diameter, whereas the polymersomes range from 10 to 35 μm. Most human cells are 10 μm.

Currently, a chemical tag made from polyethylene oxide is used to make lipid capsules and other biological delivery vehicles invisible to the immune system. The polymersomes have this polyethylene oxide tag built in.

The research team found that the polymersomes are an order of magnitude tougher than other capsules that more closely resemble natural cells. This resiliency is important for any capsule that would experience repeated stress, for example when buffeted about in the human circulatory system, they said. Discher said, "The polymersomes can withstand fluid stresses in physiological solutions for up to a month without falling apart."

The researchers furthermore said that because the polymersomes are made synthetically, scientists have wider control over the properties they can engineer. Polymersomes also mimic the way biological cells change shape in response to environmental factors, such as density or temperature. □

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WASHINGTON NEWS

Congress May Trim FY 2000 Funds for Spallation Neutron Source

The Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL) has recently been chosen as the site for the construction of the next generation Spallation Neutron Source (SNS). The SNS is a collaborative project involving ORNL and four other DOE national laboratories (Argonne, Brookhaven, Lawrence Berkeley, and Los Alamos) designed to meet the growing needs in the U.S. research community for more powerful neutron sources (see Washington News in *MRS Bulletin*, May 1998, page 9).

Increasing pressures on Congress to cut federal discretionary spending during Fiscal Year 2000 could result in a reduction in funding for SNS, now nearly one year into its design phase at Oak Ridge. The final amount of the cutback remains uncertain until the actual budget is approved in October. An interim vote in late May by the House Science Committee determined that $96-million could be slashed from the $214-million originally requested for FY 2000, according to sources on both Capitol Hill and inside DOE.

This cutback, according to DOE officials, would cause delays in the development of major SNS components, inevitably result-