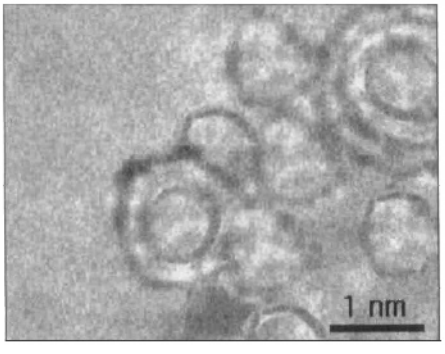
Multishell Fullerenes with Cage-Inside-Cage Structure Observed

A team of Russian and Japanese researchers working at ICMR in Japan have fabricated multishell fullerenes with a cage-inside-cage structure. Carbon blacks, heated at 3000°C, undergo restructurization in which fullerene-like multishell nanoparticles of ~20 nm size appear. With direct transmission electron microscopy (TEM), the scientists V.Z. Mordkovich, A.G. Umnov, T. Inoshita, and M. Endo observed three varieties of the cage-inside-cage clusters: two-shell 14 Å size (C_{60} @ C_{240}), two-shell 20 Å size (C_{240} @ C_{560}), and three-shell 20 Å size (C_{80} @ C_{240} @ C_{560}).

As reported in the November issue of *Carbon*, a TEM image showed nanoparticles characterized by an average size of 200 Å, with size variation within the limits of 100–400 Å. The nanoparticle wall thickness was in the range of 10–30 monolayers with an interlayer spacing of 3.39 Å. Through vacuum sublimation (temperature up to 1600°C and vacuum up to 10^{-7} Torr), the scientists produced a dull brown transparent film which showed the multishell fullerenes under TEM.

The researchers also characterized the sublimated film by other methods: x-ray diffraction showed no evidence of diffraction features, which means that the film is amorphous. Through infrared (IR) spectroscopy, they observed four lines in the range of 800–2000 cm^{-1}. They reported that the three stronger lines at 1040, 1362, and 1718 cm^{-1} may represent the higher fullerenes C_{80} and C_{180} which make up the majority in the film. The strongest C_{60} lines 1424 and 1183 cm^{-1} did not appear in the IR spectra, which indicated that the film does not contain any significant amount of C_{60} fullerenes.



High magnification transmission electron microscope image taken from a sublimated film received by vacuum evaporation of laser pyrolysis carbon black shows two-shell 14 size Å (C_{60} @ C_{240}) and two-shell 20 Å size (C_{240} @ C_{560}) fullerenes.

SEM Reveals Formation of SnI_2 and CdI_2 Thin Films in Nonequilibrium Growth

Researchers at Tsinghua University in China and the Chinese Centre of Advanced Science & Technology observed iodide thin films that give rise to fractal structures (SnI_2) or self-organizing structures (CdI_2) resulting from nonequilibrium growth processes. As reported in the October issue of *Physica Status Solidi B*, Jizhong Zhang, Xiaoyan Ye, and Xiaodong Yang recorded the influence of cooling rates on SnI_2 deposits, discovering that at 1000°C/min a transient from equilibrium to nonequilibrium growth was shown. In their study on the morphology of CdI_2 deposits, variation in saturated vapor pressure and temperature also brought about an anomalous growth mechanism.

In their experiment, the researchers prepared samples from a 75 mm silicon wafer substrate and loaded these into a deposition chamber. They chose high-purity SnI_2 powder as source material of the evaporator and applied temperatures of 520°C and 600°C for a duration of 1 h. They heated the evaporation-deposition device from room temperature to the selected temperatures at a rate of 25°C/min, and after 1 h began cooling the device to 320°C at rates of 30, 50, 300, and 1000°C/min, then from 320°C to room temperature at a rate of 25°C/min. Under a scanning electron microscope (SEM), the researchers observed fractal structures obtained after heating the powder at 520°C for 1 h and cooling it subsequently with a rate of 1000°C/min.

The SEM images exposed a SnI_2 crystal accumulation in the central zone of the deposit. This accumulation was composed of numerous SnI_2 crystals ranging in size from 170 nm to 1.7 μm. At the advancing front of the SnI_2 crystal accumulation, randomly ramified branches were observed that grew out and outspread from the edges of boundary crystals. Figure (a) shows an image of a branch that displays fractal characteristics. The researchers determined that the fractal dimension of the structure was 1.64. The fractal structures were composed of numerous SnI_2 nanograins. The researchers said that there was not any fractal structure in the region of SnI_2 crystal accumulation and that the outspreading fractal structures implied the existence of a potential distribution that was related to the growth of SnI_2 fractal structures. The researchers also said that most of the nanograins are disconnected from each other, as seen in Figure (a).

In their study of the CdI_2 system, the researchers chose high-purity CdI_2 powder as the source material. With exposure to temperatures of 520°C, 550°C, and 590°C for 1 h and 1.5 h duration, the material was heated in the evaporation-deposition device from room temperature to the selected temperature at a rate of 25°C/min, and cooled to 300°C at a rate of 50°C/min, and from 300°C to room temperature at a rate of 20°C/min. SEM images showed many sunflower-like structures—grown at a saturated vapor pressure of 6.2×10^3 Pa at 590°C for a duration of 1 h—distributed uniformly on the surface of the sample. A close view of

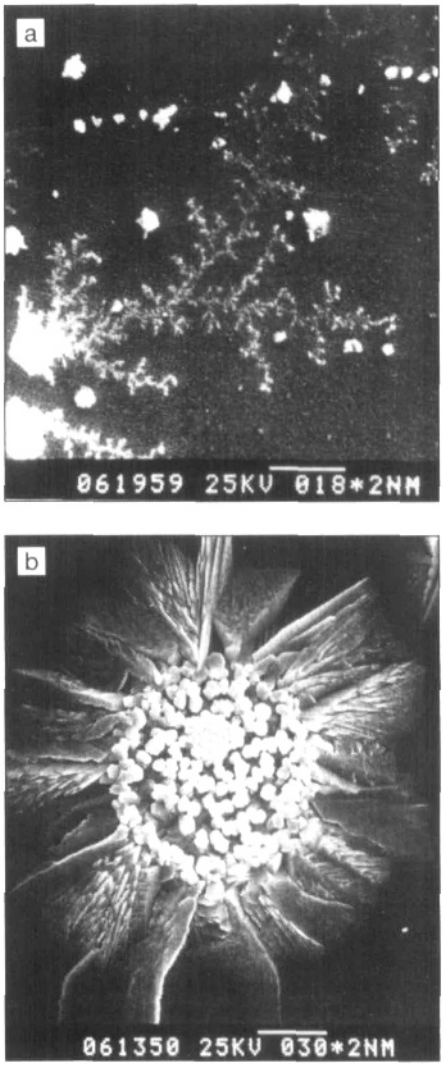


Figure (a) shows a scanning electron microscope image of a close view of a fractal branch grown out at the advancing front of SnI_2-crytal accumulation obtained at 520°C with a cooling rate of 1000°C/min; (b) shows a close view of a CdI_2 self-organizing sunflower-like structure grown at 590°C for 1 h.

the structure in Figure (b) reveals two parts. One part is the central "flower disk" which is 10 μm in diameter and composed of many oriented nanocrystals, with sizes ranging from 270 to 900 nm. The other part looks like a surrounding "petal skirt" composed of some radial elongated crystals. According to the researchers, the growth process involved the aggregation and a spontaneous cooperative behavior of CdI_2 molecules and nanocrystals. The researchers point to the long-range correlation in the experimental system as the dominant factor for forming this particular self-organizing structure.

Under a 1.5 h high-temperature exposure, the researchers discovered that the CdI_2 deposits were similar as those under the 1 h exposure; however, the self-organizing structure produced a dense "flower disk" with a size of 18.5 μm in diameter. This flower disk was much larger and denser than the one shown in Figure (b). The researchers determined that the size of the entire pattern was ~31 μm and also larger than that shown in Figure (b) because of the longer experimental duration. They did not find the self-organizing structure of this material under the other experimental parameters. They said it was difficult to obtain such structures at lower experimental temperatures because of the lower concentration of CdI_2 molecules.

C_{80} Fullerene Encapsulates Three Metal Atoms

Researchers from Virginia Tech have reported in the September 2 issue of *Nature* that they can produce C_{80} fullerenes containing three metal atoms. By introducing small amounts of nitrogen into an electric-arc reactor, the researchers produced a family of stable endohedral fullerenes encapsulating trimetallic nitride clusters, $Er_xSc_{1-x}N @ C_{80}$ (x = 0-3). Lead researcher Harry Dorn, professor of chemistry, and Steve Stevenson, a postdoctoral fellow, said that the molecule does not decompose until heated to 400°C. It then turns from black to white as the carbon burns off, leaving metal oxide particles with different properties than the original metals.

The discovery of the stable metallofullerene is a result of tracking down a small, unexplained peak of mass-to-charge ratio (m/z) of 1109 in the data that accompanied numerous analyses of fullerenes. The researchers would drill holes in graphite rods, insert metals, place them in a sealed chamber, then burn the rods with an electric-arc generator, forming carbon atom cages around the metal of choice. They said that the appearance of 1109 amu was consistent. After studying nuclear magnetic resonance (NMR) readouts and x-ray photo-electronic spectroscopy data, they recognized that the equipment was letting atmospheric nitrogen into the chamber.

Dorn said, "The arc disassociated it into N atoms. The metals latched onto the N—three atoms of metals onto one atom of N—and as it cooled, the carbon cage formed."

They obtained a molecule with a nonmetal core, the three metals, then the nonmetal cage. The researchers worked with scandium because it is well-known to go into the carbon cage and it is easily tracked with NMR. They also worked with erbium.

Biological and Nanofabrication Platforms Established for Production of Organic/Inorganic Hybrid NEMS

Coupling the organic and inorganic, biological engineers at Cornell University have demonstrated the feasibility of extremely small, self-propelled bionic machines that do their builders' bidding in plant and animal cells. The integrated molecular motor, consisting of the enzyme ATPase coupled to a metallic substrate with a genetically engineered "handle," ran for 40 min at 3–4 revolutions/s. The ATPase molecules were produced by *Escherichia coli* bacteria that were genetically engineered to include a gene sequence from the thermophilic bacterium *Bacillus* PS3. With further genetic manipulation, the engineers expect *E. coli* to turn out ATPase molecules with tiny propellers. Carlo Montemagno, an assistant professor of agricultural and biological engineering, said, "We have succeeded in establishing biological and nanofabrication platforms for the production of organic/inorganic hybrid nanoelectromechanical systems (NEMS)."

The ATPase molecular motors are found in the membranes of mitochondria as well as in chloroplasts of plant cells. The moving part of an ATPase is a central protein shaft that rotates in response to electrochemical reactions with each of the molecule's three proton channels.

ATP (adenosine triphosphate) is the fuel for the molecular motor's motion. Energy

becomes available when atomic bonds between phosphate atoms are broken during hydrolysis to convert ATP into ADP (adenosine diphosphate). During ATP hydrolysis, the tail rotates in a counterclockwise direction; it rotates clockwise during ATP synthesis from ADP.

As reported in the September issue of *Nanotechnology*, the engineers tagged the ATPase molecule's rotor with fluorescent microspheres that are 1 μm in diameter, and observed microsphere movement with a differential interferometer and with a charge-coupled device kinetics camera. The "handle" for attaching the ATPase motor to the nanofabricated metallic substrates is a synthetic peptide composed of histidine and other amino acids. The histidine peptide allows the molecular motors to adhere to nanofabricated patterns of gold, copper, or nickel—the three standard contact materials in integrated circuits. The patterned metal substrates were created by evaporative deposition.

"Our long-term objective is to utilize the best attributes of the organic and inorganic worlds for NEMS that are powered by biological motors and chemical energy sources," Montemagno said.

For an animation of the removal of F_1-ATPase from the cell membrane which included the F_0-ATPase portion, see website www.news.cornell.edu/releases/Sept99/bio_nano_mechanical.hrs.html.

Image of Electron Orbitals Confirms Controversial Bonding Hypothesis in Cu_2O

Using a combination of convergent beam electron diffraction and x-ray diffraction techniques, a team of materials researchers at Arizona State University have achieved clear images of electron orbitals responsible for bonding in Cu_2O, known as cuprite, a ceramic semiconductor with a rare structure. The images map the charge density of non-ionic bonds in Cu_2O, providing experimental verification of the controversial hypothesis that both ionic and covalent bonding occurs in the material. The images also show that the covalent bonding exists not just between oxygen and copper atoms, but also between pairs of copper atoms.

The charge-density maps show electron clouds in a distinct dumbbell shape, with a torus and two three-petaled rings surrounding the middle. This complex formation is predicted by theory for a "s-dz2 orbital hybridization," which leaves a "hole" on the copper ions. The maps also show fainter, less-defined distributions of electrons between the copper atoms in the crystal matrix, indicating the metal-to-metal bond. As reported in the September 2 issue of *Nature*, both x-ray and electron diffraction were used in the mapping. Electrons were used for small scattering angles to avoid the "extinction effect" that otherwise distorts x-ray measurements, and x-rays at high angles where they are more accurate—a combination that gave the team sufficient accuracy for the fine details of the images. The clear definition of the covalent Cu–O bonds was obtained by using a technique that first moved all ions (Cu^+ and O^{--}) to the background of the map and then subtracted the background from the image. Although the

team's maps are computer-generated, they are not simulations, but actual images produced directly from the electron diffraction results.

Chemical Surface Reaction Induced by Ultrashort Laser Pulses

Researchers at the Fritz Haber Institute of the Max Planck Society in Berlin have reported in the August 13 issue of *Science* that by using ultrashort laser pulses, they were able to "switch on" a model surface reaction which does not occur by heating the surface. They also unraveled the ultrafast speeds and mechanisms of energy flow for this reaction: the catalytic oxidation of carbon monoxide to form carbon dioxide on transition metal (ruthenium) surfaces. The researchers said that this prototype surface reaction is of interest from a technological point of view—as the key reaction in automotive exhaust catalysis, and also from a fundamental point of view—as a model reaction for understanding heterogeneous catalysis.

The researchers employed fs laser pulses to investigate the ultrafast time evolution of the reaction. After the first of these pulses initiated the reaction, they monitored its ultrafast time evolution by using the subsequent pulses, which took "snapshots" of the reaction as it evolved on the surface.

According to the article, the laser pulses are absorbed by the metal, which can be represented by two heat reservoirs: One consists of the metal electrons, the other of the vibrations of the metal atoms (also called lattice vibrations). Only the first reservoir, the metal electrons, initially absorbs the laser energy, thereby becoming very hot (several thousands of degrees Kelvin above the metal's melting point). However, it takes only about 2 ps until the electrons and the lattice vibrations have the same temperature again. The energy transfer from the two heat reservoirs to reactants on the surface determines how and why a chemical reaction occurs. During the extremely short time of different temperatures the researchers were able to determine whether the metal electrons or the lattice vibrations initiate the reaction.

In contrast to the excitation by a laser pulse, during conventional thermal heating the temperatures of the metal electrons and the lattice vibrations are always equal, so that there is no way of distinguishing which reservoir provides the energy to induce the reaction. When the ruthenium surface with CO and O is conventionally heated, no oxidation of CO molecules takes place. Instead the CO molecules are found to leave the surface at a certain temperature; the more strongly bound O atoms do not desorb.

By exciting the same surface with ultrashort laser pulses, the reaction between O and CO to CO_2 does take place: The energy from the excited hot electrons is transferred into the oxygen–metal bond. The strong bond is weakened so much that the oxidation reaction with the neighboring CO molecule becomes possible and CO_2 is formed and leaves the surface. Desorption of CO molecules occurs, as in the case of conventional heating. Therefore the oxidation reaction has to compete

with the desorption. It is by the ultrafast heating of the electrons using laser pulses and their very rapid energy transfer (on a 500 fs time-scale) into the oxygen–metal bond that the desorption process can be outpaced (the desorption is much slower, because here the energy comes from the lattice vibrations, which have to be heated by the electrons first). With the laser pulse, the system is rapidly steered into reactive regions that are normally inaccessible.

From the experimental data and with the help of advanced modeling, the researchers deduced exactly how the energy transfer from the hot electrons to the oxygen–metal bond takes place: An electron hops from the metal onto the oxygen atom, for a very short time (~1fs). A consequence of this mechanism is that by using oxygen atoms of slightly different isotopes, increasing the mass by a factor of only 1.25, the CO_2 yield was observed to drop by a factor of 2.2.

1999 Nobel Prize Awarded in Physics, Chemistry, Medicine

The Royal Swedish Academy of Sciences has awarded the 1999 Nobel Prize in Physics jointly to **Gerardus 't Hooft**, University of Utrecht, the Netherlands, and **Martinus J.G. Veltman**, Bilthoven, the Netherlands, "for elucidating the quantum structure of electroweak interactions in physics." The researchers are being awarded for having placed particle physics theory on a firm mathematical foundation. They have in particular shown how the theory may be used for precise calculations of physical quantities. Experiments at accelerator laboratories in Europe and the United States have recently confirmed many of the calculated results.

Gerardus 't Hooft received his doctoral degree in physics in 1972 at the University of Utrecht. He has been a professor of physics at the University of Utrecht since 1977. Among other awards, 't Hooft received the 1979 Dannie Heineman Prize from the American Physical Society and the 1982 Wolf Prize for his work on renormalizing gauge theories. He has been a member of the Dutch Academy of Sciences since 1982.

Veltman received his doctoral degree in physics in 1963 at the University of Utrecht, and was a professor of physics at the University of Utrecht from 1966 to 1981 and at the University of Michigan, Ann Arbor, beginning in 1981, where he is now professor emeritus. Among other awards Veltman received the 1993 High Energy and Particle Physics Prize from the European Physical Society for his work on renormalizing gauge theories. He has been a member of the Dutch Academy of Sciences since 1981.

The Academy has awarded the 1999 Nobel Prize in Chemistry to **Ahmed H. Zewail**, California Institute of Technology, for showing, in the field of femtochemistry, that it is possible with rapid laser technique to see how atoms in a molecule move during a chemical reaction. Zewail is cited for "his studies of the transition states of chemical reactions using femtosecond spectroscopy."

In his technique, Zewail uses laser flashes of such short duration that he reaches the time scale on which the reactions occur in femtoseconds. Femtochemistry explores why certain chemical reactions take place but not others. It also explains why the speed and yield of reactions depend on temperature.

Zewail studied at the University of Alexandria in Egypt. After continued studies in the United States, he received his PhD degree in 1974 at the University of Pennsylvania. At Caltech he has held

the Linus Pauling Chair of Chemical Physics since 1990.

The 1999 Nobel Prize in Physiology or Medicine has been awarded to **Günter Blobel** for the discovery that "proteins have intrinsic signals that govern their transport and localization in the cell."

A large number of proteins carrying out essential functions are constantly being made within cells. These proteins have to be transported either out of the cell, or to the organelles within the cell. Günter Blobel, a cell and molecular biologist at the Rockefeller University in New York, researches how newly made proteins are transported across the membrane surrounding the organelles, and how they are directed to their correct location. At the beginning of the 1970s he discovered that newly synthesized proteins have an intrinsic signal that is essential for governing them to and across the membrane of the endoplasmic reticulum, one of the cell's organelles. During the next 20 years Blobel characterized in detail the molecular mechanisms underlying these processes. He also showed that similar "tags" direct proteins to other intracellular organelles.

The principles discovered and described by Blobel operate similarly in yeast, plant, and animal cells. A number of human hereditary diseases are caused by errors in these signals and transport mechanisms. Blobel's research has contributed to the development of an effective use of cells as "protein factories" for the production of important drugs.

More information on this year's Nobel Prizes is available at website www.kva.se.

Anthony Kelly Receives 2000 Acta Metallurgica Gold Medal

Anthony Kelly of England, retired, has been awarded the 2000 Acta Metallurgica Gold Medal recognizing outstanding ability and leadership in materials research. Kelly's lifetime materials interest has specifically focused on the strength of solid materials. He is internationally known for his pioneering work in the field of advanced composite materials, but his interests extend to crystalline solids generally and the relations between defects and mechanical properties.

In 1973, Kelly was elected a Fellow of the Royal Society of London for his contributions to establishing the principles of fiber reinforcement of materials and for establishing some principles for distinguishing between brittle and ductile materials on a quantitative basis. He has elucidated many of the principles of precipitation and dispersion hardening of metals, and has authored major publications on the fiber reinforcement of cement, the creep of composites, the reinforcement of brittle matrices, long-term degradation of plastic composites, and in the past several years, on the design of very high temperature resistant materials and the principles of dense fiber packing.

During his career, Kelly has carried out research at the University of Illinois and Birmingham University, and worked as associate professor at the Technological Institute of Northwestern University in Chicago and as appointed lecturer at Cambridge University. He was involved as one of the founding fellows of Churchill College where he also directed Studies in Natural Sciences.

Kelly founded the European Association of Composite Materials, and he also founded the Surrey Research Park, a research site adjacent to the campus of the University of Surrey. As Vice-Chancellor at Surrey, Kelly sought to streamline administrative procedures at the University and create strong research teams which could then transfer into commercial companies.

He received major medals and prizes from the Cambridge Philosophical Society, the Institute of Materials, ASM International, and the French Academie des Sciences. He received his doctorate degree at Trinity College, Cambridge, in 1953.

Sorting System Powered by Thermal Noise Separates Membrane Molecules

Scientists at Stanford University have invented a device, which sorts molecules found in the cell membrane, that is powered by thermal noise, which is the random variations in energy found in a population of molecules at a given temperature. As reported in the August 13 issue of *Science*, the system can separate membrane molecules in their native environment continuously.

Professor of chemistry Steven G. Boxer

and postdoctoral fellow Alexander van Oudenaarden demonstrated their device, which is a type of Brownian ratchet called a geometrical ratchet that uses asymmetric barriers to harness thermal fluctuations to produce directional motion.

The researchers filled a membrane chip with an array of microscopic barriers to create a type of two-dimensional ratchet that works on membrane-associated molecules. They filled the array with artificial membrane and tested it by adding charged, fluorescently labeled phospholipid molecules to one corner. They applied a small electrical field across the array and observed the fluorescent molecules diffuse. The flow pattern showed that the device was converting Brownian movement into a net motion perpendicular to the direction of the electrical field.

The scientists also demonstrated that such a system can separate different kinds of membrane molecules by introducing two fluorescently labeled molecules, one with a single- and the other with a double-negative charge. Their measurements showed that the migration paths of the two types of molecules through the array were substantially different.

The test showed that the device can sort a large class of membrane molecules, including a number of cell surface receptors, that move freely around in a membrane when it is supported by a solid surface.

Model of Silicon Inverse Opal Backbone PBG Structure Containing Liquid Crystal Predicts Tunable Bandgap

Researchers from the University of Toronto have reported in the August 2 issue of *Physical Review Letters* their calculations indicating the ability to open or close an ≈ 2% photonic bandgap (PBG) by changing the orientation of the nematic director after infiltrating the nematic liquid crystal BEHA into the void regions of an inverse opal. They attained further tunability of the PBG by bringing about a thermally-driven nematic to isotropic liquid phase transition. Kurt Busch and Sajeev John said that "the three-dimensional PBG can be completely opened or closed by applying an electric field which rotates the axis of the nematic molecules relative to the inverse opal backbone." The model structure used by Busch and Sajeev consists of an inverse opal backbone made in silicon. Inverse opal structures are high dielectric structures interrupted by air inclusions. In their calculations, the researchers used a silicon backbone structure with a silicon volume fraction of 24.5%. The silicon backbone structure is in the form of a fcc lattice of close-packed spherical air inclusions. The space between the air spheres was assumed to be ≈ 90% filled with silicon leaving only tiny air voids between the air spheres. The inclusions in the silicon backbone were assumed to be partially filled with the nematic liquid crystal material BEHA such that the interior surface of the silicon backbone was homogeneously wetted. The total volume fraction of BEHA was assumed to be 36.8%.

Although the 8.6% photonic bandgap of the silicon inverse opal backbone is destroyed by the addition of the liquid crystal material, a pronounced pseudogap with a low density of states remains. Their calculations indicate that the photonic

bandgap is completely closed when the nematic director is oriented along the (001) axis of the fcc backbone structure. When the nematic director is oriented along the (111) direction of the fcc backbone, a three-dimensional photonic bandgap of 1.6% is opened. Along the (110) direction, the photonic bandgap is slightly more than 1.2%. Busch and Sajeev suggest that devices formed with these structures may be suitable for electro-optical modulators or for tunable waveguides as well as other electro-optical applications.

Combination of Thermal Model and Microstructure-Based Method Aids in Development of Hard Machining

Researchers at Purdue University have developed a mathematical method to aid in the development of hard machining. Currently, parts that carry critical loads are produced in many steps, including time-consuming and costly grinding and polishing operations. The parts are first machined out of metal that is relatively soft. They are then hardened upon being subjected to high heat and quickly cooled in water. After those steps, they still require precision finishing processes to make their surfaces ultrasmooth to reduce friction and wear.

C. Richard Liu, a professor of industrial engineering at Purdue, said that in superfinish hard machining, the metal is hardened first and then machined in a single-step process that yields smoother surfaces, reduces waste, and eliminates the need for polluting oils now essential for cutting and grinding. He said that one obstacle to the widespread use of hard machining is that, as the cutting tools that are used to machine hardened steel begin to wear, they cause thermal damage that weakens the metal being machined. The tools, which come in a variety of shapes, are small, sharpened bits like those used on a lathe to machine metal. Before superfinish hard-machining can be perfected, engineers need better methods to analyze precisely how heat is conducted between the cutting tool and the metal surface. They also need to take into account how much heat is released as it is carried away by metal shavings, or chips, removed from the metal during machining.

In a presentation on August 24 at the 49th CIRP General Assembly held in Montreux, Switzerland, Liu described a mathematical method he had developed to predict the precise temperature distribution at the interface of the cutting tool and the metal surface. The method consists of a thermal model based on Green's function and a microstructure-based method using orthogonal hard turning.

In the abstract of his paper using the example of tool flank wear, Liu said, "The coupling of the interface boundary conditions due to chip formation and flank wear is resolved using the proposed microstructure-based method, which is a departure from the conventionally incorrect approaches based on the assumption of constant chip formation. By incorporating the microstructure-based method with the thermal model, heat generated, heat partition, and the shear forces at the tool-chip and tool-work interfaces can be determined."

Repulsion Effect Between Quantum Dots May Govern Their Self-Organization

Scientists at Sandia National Laboratories have developed probes that measure in real time atoms clustering to form relatively large three-dimensional dots called islands. The scientists observed the role of mutual repulsion in causing dots to change shape and self-organize as they grow. The smaller the dot, the shorter the emission wavelength; the more tightly the dots are packed, the more intense the beam; and the more uniform their size, the more uniform the frequencies.

Principal investigator Jerry Floro said, "Understanding this self-organization is critical if we are to control dot characteristics for lasing devices."

The researchers used optical and stress measurements to observe dot formation as it happens on silicon germanium. Stress in the film causes the substrate to bend, which the researchers measure by bouncing laser beams off of the sample. When the dots form and change shape, the stress changes and so does the amount of bend in the substrate. Mapping the substrate as it bends reveals when dots first form and how their shapes evolve.

Floro said, "We directly measure the kinetics of nucleation, coarsening, self-organization, and phase transformations within growing island arrays. All these processes are explained within a unified model that works with ensembles of islands rather than individual islands in isolation."

As reported in a series of articles in *Physical Review Letters* and in an invited talk by Floro at the Gordon Conference on Thin Film and Crystal Growth Mechanisms, in Plymouth, N.H. this past summer, 10 atomic layers of film would form smoothly, then as more layers were deposited, the film broke up into tiny pyramid-shaped islands. With more layers, the pyramids self-organized and coarsened, and then became dome-shaped islands.

During measurement, the dots were treated as the originators of light-interference patterns. Since light's direction and intensity varies depending on the size, shape, and spacing of the islands, the results offer information in real time to determine what is happening to the tiny islands as temperatures, material compositions, and stresses change.

"We realized that if we could produce islands more than 1,000 Å across, the spacing between islands was like that of a diffraction grating," said Floro. "Combined with our real-time stress observations, this allowed us to measure stress, shape, and size simultaneously instead of having to stop the process, take the dots out, and measure them. A key ingredient was our ability to show that the basic physics of the large islands mimics that of the much smaller dots."

Observing the process of dots going from one shape to another to relieve stress provided insight into the physics governing island formation. Floro said that it showed what controls dot evolution, and how process conditions like temperature and strain enhance or suppress dots.

The researchers said that while silicon germanium is not a good laser emitter, it is simple enough to derive the applicable physics. Floro said, "We next need to find out how much of the physics learned in silicon germanium will apply to real laser materials like indium gallium arsenide. If we can understand the physics, we can make better quantum dots."

Mid-Infrared Saving of Coulomb Energy may Explain High-Temperature Superconductivity in Cuprates

A "midinfrared" scenario may help explain the mechanism behind high-temperature, cuprate (copper-containing) superconductors according to theorist Anthony J. Leggett, the John D. and Catherine T. MacArthur Professor of Physics at the University of Illinois. He said, "Superconductivity in the cuprates could be caused by a saving of the Coulomb energy associated with long wavelengths and midinfrared frequencies. This saving of Coulomb energy is a natural result of the formation of Cooper pairs, but is not included in the BCS theory, or most generalizations of it; it may be specially important in very 'two-dimensional' materials like the cuprates."

The BCS theory—developed in 1957 by John Bardeen, Leon Cooper, and John Schrieffer—explains superconductivity at temperatures close to absolute zero, but has difficulty accounting for the higher temperatures that were later achieved with the cuprates. According to BCS theory, electrons called Cooper pairs can be attracted to one another through interactions with the crystal lattice. These electrons can share the same quantum-wave function, which results in a lower energy state for the superconductor.

Cooper-pair production in the cuprates,

SBIR Update

Reaction Design (San Diego, California) received a $75,000 Phase I Small Business Innovative Research grant from the National Institute of Standards and Technology to fund a six-month proof-of-concept work on advanced chemical modeling and simulation for semiconductor processing.

Joseph F. Keithley, a pioneer in the field of electrical measurement science, died October 1 after a long illness. He was 84. Keithley was considered by his industry as one of the key figures who founded the electrical test and measurement field immediately after World War II. His achievements are tied mainly to his company, Keithley Instruments, which he started in 1946 as a one-man business. Keithley began making products capable of measurement precision and sensitivity. His first product was an amplifier for low-level electrical signals that he called the Phantom Repeater, a product he sold with some success until a friend suggested that he apply his low-level measurement skills by building an instrument called an electrometer. Keithley had said that he did not know much about electrometers then, but had since then developed his company into a major producer of instruments used for measuring low levels of voltage and other electrical measurement tools. In 1998, the company employed more than 500 people and posted sales of $118 million.

Keithley received numerous honors for his work, including the Medal of Excellence in Applied Science, Engineering, and Technology, presented by Vrije Universität Brussels (1996), the Cleveland Engineering Society's Leadership Award (1996), the Institute of Electrical and Electronics Engineers (IEEE) Centennial Medal (1984), and the U.S. Navy's Distinguished Civilian Service Award (1945). In 1992 he was named as a member of the National Academy of Engineering for "unusual accomplishment in new and developing fields of technology," and in 1998 the American Physical Society created an award for Measurement Science named for Joseph F. Keithley.

Keithley was an activist in terms of investing in the future of technology and engineering. He fostered close links between his company and Case Western Reserve University (CWRU) and the Massachusetts Institute of Technology (MIT), his alma mater. He and his wife have endowed chairs at Carnegie Mellon University, MIT in electrical engineering, and at CWRU in technology management.

however, is probably not dependent upon the crystal lattice, Leggett said. Instead, electrons may form Cooper pairs because of a net saving of Coulomb energy.

Leggett hypothesized that the driving force leading to superconductivity in the cuprates is the saving of Coulomb energy in the regime of long wavelengths and midinfrared frequencies. He said, "The main effect of Cooper-pair formation in this region is to reduce the force of repulsion between electrons, which results in a net saving of Coulomb energy."

Leggett said that whether the Coulomb energy is being saved in the midinfrared region could be answered directly by differential electron-energy-loss spectroscopy (EELS) measurements. He said that EELS cross-section is a direct measure of the Coulomb energy locked in the region. As reported in the July issue of the *Proceedings of the National Academy of Sciences*, the midinfrared scenario predicts a large decrease in the EELS cross-section in the midinfrared region when the material undergoes a transition from the normal state to the superconducting state.

Light Emission During Fracture of Metallic Glasses May be Due to Pyrolysis of Materials at the Site of Fracture Initiation

In a study of light emission observed during dynamic fracture of a bulk metallic glass, $Zr_{41.2}Ti_{13.8}Cu_{12.5}Ni_{10}Be_{22.5}$, researchers at the University of California—Berkeley have determined that the intense light emission in air is associated with pyrolysis of fresh materials exposed during rupture. According to their report in the June 1999 issue of *Applied Physics Letters*, C.J. Gilbert, J.W. Ager, V. Schroeder, R.O. Ritchie, J.P. Lloyd, and J.R. Graham examined these Zr-based amorphous alloys machined from as-cast plates into Charpy V-notch impact specimens (50 mm × 10 mm × 8 mm). They dynamically fractured the samples in room air and in nitrogen gas with a pendulum velocity of ~3.5 m/s at impact. They collected spectra over a visible range (350–925 nm) with a liquid nitrogen cooled charge-coupled device (CCD) camera and in the near infrared using a liquid nitrogen cooled HgCdTe detector. They used a scanning electron microscope to examine fracture surfaces produced in both air and nitrogen.

The researchers observed bright streaks, suggesting that light emission is associated with the ejection of hot particles from the fracture surface. They reported that in room air the emitted spectrum showed a broad peak with no sharp features, fit to a blackbody temperature of 3175 K. In nitrogen, the signal intensity was reduced by over four orders of magnitude. A regression fit to the leading edge of the visible spectrum showed a much lower blackbody temperature of 1400 K. SEM revealed that in both types of environment, the melted features existed only near the root of the notch—within the first ~250 μm—where fracture initiated.

The scientists conclude that in air the light emission and blackbody temperature are tied to oxidation of freshly exposed material following fracture and that the suppression of light emission in nitrogen, along with the drop in temperature, most likely results from the decreases in oxygen partial pressure. □