## Nanometer Cobalt/Copper/Cobalt Device Forms Controllable Magnetic Switch

In passing a small electric current through a sandwich of two layers of magnetic material separated by a copper conductor, researchers at Cornell University demonstrated a way to controllably switch the magnetic orientation of a small area. As described in the August 6 issue of *Science*, the researchers created two thin layers of cobalt separated by a copper spacer. The upper cobalt layer is less than 10 nm thick, the copper layer is 4 nm thick, and the lower cobalt layer is ~100 nm thick. A tiny copper electrode touches the top of the upper layer. The initial experiment was conducted in an apparatus cooled to 4.2 degrees above absolute zero by liquid helium. In later work, the researchers demonstrated the same effect at room temperatures.

By passing an electrical current perpendicularly through the layers, the researchers were able to reverse the orientation of the magnetic moments in a region of the thinner cobalt layer, while leaving the thicker layer unchanged. The result was that the north and south poles in the two layers pointed in nonparallel directions. Reversing the current flipped the thin layer back so that the moments in the two layers were again parallel.

The orientation of the magnetization in the two layers can be read by passing a much weaker electric current through the two layers because the resistance is much higher when the two moments are nonparallel. This means the effect could be used to create a computer memory chip in which each tiny magnetized area represents a "one" when the moments are parallel or a "zero" when they are opposed.

The effect works, the researchers said, because electrons passing through a magnetic material are spin polarized, meaning that they are spinning in the same direction, with their axes lined up. When the electrons previously polarized by passing through the thick magnetic layer collide with the thin one, they apply a twisting force that can cause the magnetic moment in that layer to switch orientation. Electrons that pass through the thin layer first are reflected back off the thick layer, with reversed polarization, to have the same effect.

Such an effect was predicted by John Slonczewski, a theoretical physicist at the IBM research laboratory in Yorktown Heights, N.Y. Previously the only means by which the magnetic poles could be reoriented in magnetic devices was through the application of an external magnetic field.

Dan Ralph, Cornell assistant professor of physics, said that the simple switching effect only occurs in films 4 nm thick or less. With thicker films, spin-polarized currents induce more complicated motions of the magnetic moments, yet to be studied in detail.

## High-Pressure Measurements and First Principles Calculations Indicate Cubic $Si_3N_4$ May Have Hardness Close to Stishovite

A phase of silicon nitride with a cubic spinel structure, designated as c-$Si_3N_4$, was synthesized and identified by scientists of the High Pressure Group at the Max Planck Institute for Chemistry in Mainz, from the Technische Universität Darmstadt, and Cornell University in Ithaca. The researchers embedded silicon single crystals in a nitrogen pressure medium in a diamond cell. A Nd:yttrium-lithium-fluoride (YLF) laser was used to heat the silicon probe up to 2200 K at a pressure of 15 GPa. The reaction product was examined by Raman spectroscopy, by transmission electron microscope, and by electron dispersion x-ray analysis.

As reported in the July 22 issue of *Nature*, the investigations showed a cubic silicon nitride phase of space group *Fd-3m* ($Z = 8$) with a spinel structure where both tetrahedrally and octahedrally coordinated silicon atoms with a 1:2 ratio are contained.

The c-$Si_3N_4$ is stable at high temperatures and at pressures between 15 and 30 GPa; at ambient pressure in air it persists metastably to at least 700 K. It was also synthesized from amorphous $Si_3N_4$ as well as α- and β-$Si_3N_4$—two hexagonal polymorphs of $Si_3N_4$—in a diamond cell at 15 and 30 GPa on heating up to 2800 K with a $CO_2$ laser.

Both α- and β-$Si_3N_4$ have a density of about 3.2 g/cm$^3$. The α-$Si_3N_4$ can be synthesized from silicon and nitrogen at ambient pressure and temperatures below 1800 K, while the β phase requires higher temperatures. The β-$Si_3N_4$ is also obtained from α-$Si_3N_4$ at about 5 GPa and 2270 K using an internally heated high pressure vessel.

For c-$Si_3N_4$ with spinel structure the calculated density is 3.93 ± 0.12 g/cm$^3$, a value 23% higher than that of α- or β-$Si_3N_4$. First-principles calculations of the compressibility and the elastic $c_{44}$ modulus of c-$Si_3N_4$, which are related to its hardness, yielded 300 and 340 GPa. Because these values are comparable to those of stishovite (281–313 GPa and 252 GPa, respectively), a hardness of c-$Si_3N_4$ close to that of stishovite can be expected. Stishovite, a high pressure modification of $SiO_2$, where the silicon atoms are octahedrally coordinated to oxygen, is considered to be the third hardest material (Knoop hardness of 33 GPa) after diamond and cubic boron nitride. According to the researchers, the expected hardness and the metastability of c-$Si_3N_4$ make it a promising material for technological applications, especially in the cases where diamond cannot be used.

## Imaging Microscope Analyzes Various Materials in Real Time

A group of researchers led by Dor Ben-Amotz, a chemistry professor at Purdue University, has developed a near-infrared Raman imaging microscope, called NIRIM, which uses laser light to analyze composite materials thousands of times faster than current methods. The instrument uses Raman scattering to fingerprint a sample as it is being viewed under a microscope. To map the distribution of chemical species present in a sample, the instrument uses an optical fiber-bundle image compression technique.

"An optical spectrometer measures the wavelengths of different colors of light, ranging from red to violet," Ben-Amotz said. "In the case of Raman spectroscopy, the resulting colors come from the vibrations of molecules. Because each molecule has a unique pattern of vibration—determined by its chemical structure—we can use this method to fingerprint different types of chemicals."

According to Ben-Amotz, several scanning methods have previously been used to generate Raman images, but these methods, slowed by the need to collect data one wavelength at a time, cannot collect a complete Raman image in real time.

He said, "All of these instruments, including ours, rely on a two-dimensional

### SBIR Update

**Symyx Technologies, Inc.** (Santa Clara, California) has been awarded a Department of Energy Phase II Small Business Innovative Research grant toward accelerating the search for novel anode materials for use in a direct methanol fuel cell.

**Materials Resources International (MRi)** (North Wales, Pennsylvania) has been selected by the Ballistic Missile Defense Organization to receive a Phase I SBIR grant to demonstrate its ceramic/metal joining technology for joining metal matrix and ceramic composites.

array detector to collect spectral data from various spatial locations, while a Raman image is a three-dimensional data cube. This means that a method for slicing sequentially through the cube, in order to read the data in two dimensions, is usually required, and that is very time-consuming."

As reported in the August 1999 issue of the *Journal of Raman Spectroscopy*, the fiber-bundle image compression method speeds the process by compressing all the data from the three-dimensional data cube into a single detector frame, allowing all points on the sample to be read in a single pass. For each sample, the instrument analyzes 100 spatial points, analyzing the chemical identity of a thousand different colors for each point. For large images, the detector uses a computer-controlled system to develop a composite image from several smaller images.

The researchers demonstrated NIRIM using a white light image of a bar-target with about a 1.0 $\mu$m spatial resolution as well as Raman chemical images of samples containing fructose/sucrose and $Pb(NO_3)_2/K_2S_{04}$ microcrystalline mixtures. For a three-dimensional data cube containing 322 image resolution elements and 900 Raman shift wavelengths, the image was collected in as fast as one second (total detector integration time).

The instrument, however, has difficulty acquiring images with a large number of points. Ben-Amotz said, "Because our technique takes smaller images—in the sense of fewer spatial points—it's harder to acquire images with a large number of points. It can be done, but it takes longer and becomes almost equivalent to the other methods."

## Spatial Imaging Resolution Below the Diffraction Limit Allowed by Picosecond Fluorescence Technique

The resolution of focusing light microscopes has been traditionally limited by the wave nature of light. As reported in the July 15 issue of *Optics Letters*, this limit was overcome by scientists at the Max Planck Institute (MPI) for Biophysical Chemistry in Göttingen, Germany, by using two laser beams in which one beam illuminated the sample while the second beam sculpted the fluorescence spot generated by the first.

In biological research, use of the focusing light microscope is the only way to allow the imaging of intact transparent specimens in three dimensions, especially when tagged with fluorescent dyes. However, its resolution is hampered by diffraction. Thomas A. Klar and Stefan W. Hell of MPI reported that in order to inhibit the fluorescence from its rim, the fluorescence spot must be decreased.

To sculpt the fluorescence spot, the researchers used two beams of different colors, each of them involving picosecond pulses. Whereas the first pulse excites the fluorophore, the slightly red-shifted pulse is able to induce the effect of stimulated emission. The stimulated emission forces the molecules to the ground state by carrying away their energy. So the stimulating red pulse instantaneously "cools off" the excited fluorophore without destroying it. By moving the stimulating pulse to the rim of the excitation spot, the researchers switched off the fluorescence from the outer part of it. The researchers reported that "for a 1.4 aperture and a 388-nm excitation wavelength spatial resolution is increased from 150 ± 8 nm to 106 ± 8 nm with a single offset beam." They said that they achieved superior lateral resolution by separation of adjacent Pyridine 2 nanocrystals that are otherwise indiscernible.

## Theory Demonstrates Removal of Vortices by Ratchet Effect in Superconductors

Lines of trapped magnetic flux called vortices have impeded the application of superconductor devices. Vortices dissipate energy and generate internal noise in these devices. In the July 22 issue of *Nature*, Albert-Laszlo Barabasi, associate professor of physics at the University of Notre Dame, proposed applying an alternating current to a superconductor that has been patterned asymmetrically in a kind of sawtooth or ratchet-like pattern. The pattern, working in concert with the alternating current, directs the vortex away from the superconductive device.

When ac current is not desired for specific applications ac current can be used to flush out vortices before the actual application begins, Barabasi said. Otherwise, if the superconducting device is driven by alternating current for the desired application, the vortices will be eliminated continuously during the normal operation of the device.

## Microbes Exposed to Solutions of Hexavalent Chromium and Toluene Vapor Reduce the Metal to a Less Toxic State

Hoi-Ying Holman and her colleagues have discovered that microorganisms living in the pores and crevices of dry basaltic rock are able to reduce a toxic form of chromium to a much less toxic form. Holman's research group at Lawrence Berkeley National Laboratory examined core samples from beneath the Radioactive Waste Management Complex at the Idaho National Engineering and Environmental Laboratory. By using infrared spectromicroscopy, the researchers were able to follow the reduction of toxic metals among populations of living organisms on minerals.

Holman, a chemist and engineer with Berkeley Lab's Earth Sciences Division and the Center for Environmental Biotechnology, said, "We have shown that organic vapor may accelerate the transformation of mobile, toxic chromium pollutants into less mobile, less toxic, stable compounds. This should help in the design and implementation of environmentally benign remediation techniques for cleaning up mixed waste sites."

As reported in the October/November issue of the *Geomicrobiology Journal*, the researchers isolated and purified 85 strains of microorganisms, many tolerant of hexavalent chromium and able to reduce it—especially in the presence of toluene ($C_7H_8$), another of the site's contaminants, which is a common product of leaking fuel tanks.

These chemical reactions typically proceeded through one or more steps, and many of the organisms encountered bottlenecks that slowed the process. One strain of bacteria, Arthrobacter oxydans, emerged as the most effective.

Arthrobacter oxydans tends to concentrate in areas rich in magnetite, an iron-oxide compound common in basalt. In order to eliminate the possibility that the magnetite itself was responsible for the reduction, the researchers tested to see if reactions would proceed on sterilized magnetite under realistic environmental conditions: in an aerobic atmosphere, at room temperature, and in the dark. Arthrobacter oxydans was reintroduced on some of the sterilized magnetite samples. Dilute chromate solution was applied to both the abiotic (barren) and biotic (inhabited) magnetite samples; in a separate set of tests, the samples were also bathed in a tenuous vapor of toluene.

Over a five-day period, the researchers applied Fourier-transform infrared spectromicroscopy to observe the steps in the reduction process and the precise location of reduced chromium. Holman said, "We identified markers in this spectral region that tracked the key compounds that undergo changes. We could resolve the spectrum in time, to follow the different steps of the reduction, and also in space, to see exactly where the reactions were happening."

On the samples with no living bacteria,

no changes were evident. On samples with living Arthrobacter oxydans, in the absence of toluene, chromium reduction was weak. But where Arthrobacter oxydans had been exposed to toluene, infrared spectromicroscopy showed that hexavalent chromium and toluene had been replaced by pentavalent chromium and products of hydrocarbon degradation, in association with biomolecules, where the bacteria were concentrated.

The researchers then studied natural communities by studying slices from basalt cores. Over a period of four months, the slices of native rock, with their resident communities of microbes still in place, were exposed to solutions of hexavalent chromium and toluene vapor. According to the researchers, infrared spectromicroscopy initially showed no evidence of reduction, and many of the organisms were apparently dying. After four months, however, chromium-tolerant and chromium-reducing natural microorganisms were seen in association with trivalent chromium. The reduced trivalent chromium state was confirmed by x-ray absorption fine structure (XAFS) spectroscopy.

## Fauchet Elected as Fellow of APS and OSA

Philippe Fauchet, professor and chair of the Department of Electrical and Computer Engineering at the University of Rochester, was recently elected a Fellow of the American Physical Society (APS) and the Optical Society of America (OSA). Fauchet's dual fellowship reflects his ability to explore many disciplines with his varied research interests. Fauchet is also professor of optics, senior scientist at Rochester's Laboratory for Laser Energetics, and director of the Center for Future Health.

His most recent efforts have helped to establish the Center and enable it to create low-cost devices for personal health care and disease prevention. Such visionary devices include a melanoma monitor and memory glasses that prompt and instruct a person suffering from memory loss by identifying people and objects, such as the contents of a shopping list.

Fauchet's research has also contributed significantly to optoelectronics. In the early 1990s, his research team combined porous silicon and a conventional silicon transistor to fabricate optoelectronic chips, and the team discovered a way to chemically strengthen the material.

Along with receiving the Guibal-Devillez Prize from the Faculté Polytechnique in Belgium for his published work on porous silicon, Fauchet has received a Sloan Research Fellowship, a Presidential Young Investigator Award from the National Science Foundation, and an IBM Faculty Development Award. At the Materials Research Society, he was a 1983 Graduate Student Award recipient and he has served as a Meeting Chair for the 1993 Fall Meeting and as a 1998 Volume Organizer of *MRS Bulletin*. Fauchet received his PhD degree in applied physics in 1984 from Stanford University.

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Letters must include your full name, institution, address, phone number, and e-mail if available.

## MacArthur Foundation Grants 1999 Fellowships

The John D. and Catherine T. MacArthur Foundation has named 32 Fellows for 1999. The Foundation is a grantmaking institution dedicated to helping groups and individuals foster societal improvements. It supports research, policy development, dissemination, education and training, and practice. Fellows receive stipends ranging from $200,000 to $375,000 over five years in order to pursue their project where they are free to focus on more than one area through interdisciplinary work.

Among the recipients is **Jillian Banfield**, a mineralogist at the University of Wisconsin, who has contributed fundamental insights into the physical and chemical forces that shape the earth's surface. Her structural studies reveal the mechanisms of rock weathering, helping to explain how elements such as toxic heavy metals can accumulate within soil. Banfield has shown that certain microbes living between rocks exert profound chemical effects on those rocks, both at the surface and deep below. These observations may lead to an enhanced understanding of soil and sediment formation, factors affecting water quality, and environmental processes. Banfield received her PhD degree in 1990 from The Johns Hopkins University, where she was a Fulbright Scholar. She is also the recipient of the Department of Energy's Award for Outstanding Research (1995).

**Carolyn Bertozzi**, a chemist at the University of California—Berkeley, has made important contributions to understanding how cells interact. She has developed a method for tricking cells into expressing non-natural sugars on their surface, which can be subsequently modified chemically to suit experimental design. In one line of research, as a member of the Materials Sciences Division at UC—Berkeley, Bertozzi and her research group manipulated cells into manufacturing oligosaccharides with ketones on the cell surface. Because the ketone group reacts strongly with other functional groups, Bertozzi's team hoped this reactivity would give ketone-labeled cells a selective affinity for materials that had been outfitted with the hydrazide group, such as ceramics, organic thin films, and metals. Bertozzi received her PhD degree (1993) from UC—Berkeley. In 1997, she was named a Pew Scholar in the Biomedical Sciences and received the Horace S. Isbell Award from the Carbohydrate Division of the American Chemical Society.

**Laura Kiessling**, a chemist and biochemist at the University of Wisconsin, has developed innovative organic syntheses that enhance the understanding and control of inflammation. Her research group synthesized multivalent ligands called neoglycopolymers that can aggregate specific inflammation-mediating proteins known as selectins, causing them to shed from the cell surface. Kiessling employed ring-opening metathesis polymerization (ROMP) to test the ability of several different glycoprotein mimics to inhibit binding to some selectins. This experimental strategy allows her to measure binding under both static and dynamic rolling conditions; the latter better mimics the physiological conditions of blood flow. She is also using this strategy to make compounds that can reorganize signaling proteins at the cell surface. These compounds can modulate how

cells respond to external signals. Kiessling received her PhD degree (1989) in chemistry from Yale University. She has received young investigator awards from the National Science Foundation and the Arnold and Mabel Beckman Foundation.

**Juan Maldacena**, a physicist at Harvard University, works in the field of string theory, which postulates the existence of fundamental constituents of matter too small to detect with current experimental apparatus. He recently postulated a critical theoretical link between the four-dimensional structure of quantum chromodynamics (QCD) and a 10-dimensional theory based on strings. By identifying a plausible method for explaining the earlier QCD theory in the context of the newer, but theoretical field of string theories, Maldacena's work holds out the promise of a "grand unification" of all known physical forces. Maldacena received his PhD degree (1996) from Princeton University. He supplemented his graduate studies in theoretical physics with a one-year research assistantship in experimental high energy physics, generating data analysis in support of the Superconducting Supercollider project.

## Takayanagi Receives 1999 Surface Structure Prize

Kunio Takayanagi, a professor of physics and materials science at Tokyo Institute of Technology, has been awarded the Surface Structure Prize for 1999 from the International Conference on the Structure of Surfaces (ICSOS) for outstanding achievement in the field of surface and interface structure. The citation said that Takayanagi was awarded the prize "for his quantitative determination of the atomic geometry of Si(111)-(7×7). This is the singularly most important structure determination in all of surface science. It brought together fragmentary results from a host of other techniques into a single coherent structure that has withstood the test of time and revealed the amazing complexity of new two-dimensional compounds formed at semiconductor surfaces. It resolved an intense controversy about the structure that had continued for nearly three decades. It was a 'tour de force' of experimental sample preparation. It led to significant new insights into the energetics of semiconductor surface reconstructions, especially as contrasted with the Ge(111)-(2×8) structure. This surface structure determination is, overall, an amazing accomplishment of truly historic proportions."

After receiving his PhD degree in 1976 from the Tokyo Institute of Technology, Takayanagi held a Humboldt Fellowship at the Fritz-Haber Institute in Berlin during 1977–1979. He joined Tokyo Institute in 1989 and is director of the Particle Surface Project being funded by ERATO (Exploratory Research for Advanced Technology) and the Japan Science & Technology Corporation. Among his awards is the Nishina Prize from the Physical Society of Japan.

## Simulations Demonstrate that High-Efficiency Materials in Air Filters Perform at Low Speed

Devices that contain air filters may have to run at slower speeds if they use new, high-efficiency filter media to their full potential, according to a study at Ohio State University. The study revealed that at high airspeeds, dust particles or other contaminants are likely to build up

on the front of a filter that utilized the new materials, instead of spreading through the whole filter. Also, smaller particles will have a higher chance of blowing through the filter material and escaping through the exhaust air. Kambiz Vafai, professor of mechanical engineering, said that manufacturers of vacuum cleaners and other air-filtering devices can sidestep this effect by running their products at lower speeds or increasing the size of the filter. Either change would help contaminants spread more evenly throughout a filter.

As reported in the March 1999 issue of the *Journal of Fluids Engineering*, Vafai and graduate student James Giuliani ran computer simulations of contaminant particles catching on porous, nonwoven glass microfiber material typical of high-efficiency filter media. Such media resemble tangles of Fiberglas, although the filter fibers are much smaller.

The researchers modeled the flow of particles around a single fiber and then expanded their calculations to include the effect of surrounding fibers. They calculated where contaminant particles—similar to typical dust particles—would stick to individual fibers at different airspeeds. Vafai said that this would also hold true for other contaminants such as soot or waste particles from chemical or manufacturing processes.

The simulations revealed that at high airspeeds, contaminant particles were more likely to contact the fibers at an angle instead of covering them in a more uniform manner. The particles' angle of impact increased with airspeed so that particles tended to pile up in specific locations instead of depositing uniformly around the fiber.

The particles formed long, narrow tendrils, which grew longer and narrower as air velocity increased. As airspeed increases, such tendrils could break off. Although the researchers did not calculate a specific airspeed at which this would happen for the purposes of this research project, Vafai estimates that such an effect would begin to happen when airspeed through a filter reached approximately 8 ft/min.

Vafai said the dendrites would form a thick layer of contaminant in the front of a filter which would not only block air flow, but also shorten the lifetime of the filter. He thinks manufacturers of devices that contain air filters could lengthen that lifetime by lowering the velocity of air through the filter media. The results hold implications for manufacturers of vacuum cleaners who want to add high-efficiency filters to their products. Vafai estimated the typical airspeed through a vacuum cleaner filter at approximately 15 ft/min, much too fast for the new filter material to operate efficiently.

"Originally, these high-efficiency filter materials were designed for lower airflow, but many manufacturers are trying to retrofit or design new devices that operate at higher airflow," said Vafai.

He said that manufacturers were limited to less efficient filter materials in the past, and had to design their devices to run at higher speeds to compensate.

"In general, more air through a filter means more contaminants removed," Vafai said, meaning more particles are pulled through the filter and get trapped inside. "Our research suggests that high-efficiency filter materials won't perform better at high speeds," he said.

According to Vafai, these results would have an impact on nuclear facilities and chemical and metallurgical plants which have used air filters to capture particles of waste products suspended in gas. □