2002 INDUSTRIAL PHYSICS FORUM
REPORT

New Tools for New Materials

October 27-29, 2002, Williamsburg, Virginia

The National Research Council's report, *Physics in a New Era*, identifies the creation of new materials as one of six grand challenges for 21st century physics. Specifically, it predicts that "novel materials will be discovered, understood and employed widely in science and technology." A critical component to meeting this challenge is the development of unique new tools for materials characterization and synthesis, a topic that provided the thematic underpinning of the 2002 Industrial Physics Forum, hosted by Jefferson Lab.

About Jefferson Laboratory

Jefferson Laboratory is funded by the Department of Energy's Office of Science for nuclear physics. The lab offers unique capabilities for elucidating the quark structure of matter, and is a resource in superconducting radio frequency (SRF) and related accelerator technologies, which can be used to create pioneering new tools for materials characterization. Chief among these tools are the world's most powerful tunable lasers: free-electron lasers (FELs), based on the lab's superconducting radio frequency technology. Unlike conventional lasers, FELs can be tuned through a range of wavelengths, and promise substantial advantages for a broad range of applications. "All research science is mission driven to improve the human condition, either by pushing back boundaries of knowledge," said Director Christoph Leemann in his welcoming remarks. "Ten years ago, we championed what was then a fledgling technology — rf superconductivity — which has made great strides since. The FEL is an outgrowth of that technology."

Theme Session: New Tools for New Materials

Fred Dylla, the FEL program manager at Jefferson Lab, summarized the history of this unique technology, and provided an overview of the FEL's achievements and future goals for the FEL User Facility. The Infrared Demo FEL began operating in 1999, producing a record-breaking 1.7 kilowatts. Conventional FELs typically transform only about 1% of the "driver" electron beam's energy into light. Rather than waste the remaining 99%, the IR demo FEL recycles the electron beam through the driver accelerator and recaptures most of the unspent energy as radio frequency power. Scientists at Brookhaven National Laboratory and Cornell University are currently designing new light sources using this capability. The transformation of electron-beam energy into laser light takes place in the FEL's optical cavity. The IR Demo's optical cavity supports not only high-power lasing at the cavity's fundamental mode, but also the generation of laser light at the second, third and fifth harmonics, an extra capability that increases the instrument's versatility.

Jefferson Lab is currently preparing for the next-generation FEL technology with a series of upgrades in progress. Hardware includes a new injector, which will double the electron-beam current, bringing it to 10 milliamperes. The IR Demo's driver accelerator has one cryomodule containing eight superconducting accelerating cavities, and a second cryomodule will be added. As a result of these additions, the driver will provide an electron beam to the laser at 160 MeV instead of 48 MeV, which translates into 10 kilowatts of infrared light. However, just as the 1 kilowatt IR Demo actually yielded more than 2 kilowatts, Dylla expects the upgraded FEL to push towards 20 kilowatts. The upgraded FEL will look much like the originally schematically, but with a new IR wiggler magnet and optical cavity placed in the return side instead of the side containing the driver accelerator. Thanks to active control of the mirror radius of curvature in the optical cavity, plus high-quality coatings, powers up to 25 kilowatts will be manageable in the upgrade's IR optical cavity, with powers up to 1 kilowatt on the UV side. Most importantly, the upgrades represent a giant step in the lab's goal of lowering the cost of producing light. Dylla estimates that light at 1 kW from the IR Demo costs about a dollar per kilojoule; the upgraded FEL will bring that cost down by a factor of 5, to about 20 cents per kilojoule.

In the long term, the FEL program seeks to lower the cost of laser light, to increase lasers' capacity for supporting research, industrial work, and defense functions; to throw open access to a wide range of useful individual colors of infrared and ultraviolet laser light; and to give laser users the tremendous advantages of applying the light in extraordinarily brief pulses. An active user community is already using the FEL for both applied and basic research. Current development efforts target industrial applications in plastics, synthetic fibers, advanced materials and metals, as well as components for electronics, microtechnology, and nanotechnology. Prospective products include surface-modified polymers for high-strength composites and for easily recyclable beverage and food packaging; corrosion-resistant metals with increased toughness; mechanical and optical components with precisely micromachined features; microcircuity; and electronics for use in harsh conditions. "FEL users/partners expect additional applications to evolve along with the technology itself — and along with the advances in basic understanding of light interacting with matter that FELs provide," said Dylla.

According to Michael Kelley, applied research program manager at Jefferson Lab and a Joint Professor of Applied Science at the College of William and Mary, the Jefferson Lab FEL offers several key advantages for potential commercialization: it is spatially selective, easily controllable, high intensity, safe, and chemically selective. Present implementations for processed light include metal cutting and welding, inkjet printer head orifices, and printing wiring board circuit paths. However, low power FELs are expensive. The cost drops dramatically as power levels rise; in fact, Kelley estimates that technological improvements can reduce the cost of FEL light by at least a factor of three below simple estimates obtained from scaling the Jefferson Lab IR Demo FEL..

Once upgrades are complete, the Jefferson Lab FEL will provide a lower unit cost of light than any other laser technology. Attaining low unit cost opens the door to large-scale manufacturing operations utilizing tens of kilowatts of average power of tunable laser light from the infrared to ultraviolet wavelengths. Therefore, "We should explore potential market opportunities, and enlist partners to develop the most promising applications," said Kelley. Opportunities include providing FEL services to manufacturers through outsourcing, for such applications as antimicrobial nylon. "Amines are effective killers of a wide range of microbes, including anthrax spores," said Kelley. "Irradiating nylon surfaces at 180-200 nm wavelengths converts it to a bioactive, strongly amine.” Another possibility is providing dedicated onsite FELs owned by the users at their manufacturing sites.

Laser microfabrication of materials that are difficult to deposit or machine by ordinary means, such as glass ceramic and polymers, enables the design and fabrication of micro-engineered aerospace structures such as complete satellites weighing less than 1 kG. Henry Helvajian, a senior scientist with The Aerospace Corporation, described recent advances towards realizing these “space argosies with magic sails,” an allusion to the poetry of Tennyson. In the 1980s, the concept of the Global Positioning System required multiple satellites, leading to the development of improved manufacturing processes for those satellites, most notably serial assembly line techniques, but “Ideally, we would like a batch production technique using parallel processing for the assembly of small spacecraft working together,” said Helvajian. This would speed the development of new projects such as Pico-SAT, a large constellation of miniature satellites, six of which are already in orbit. Also needed is the miniaturization of functionality to better integrate subsystems and packaging; the use of lighter materials, preferably those where a manufacturing technique exists for large-area processing; and multifunctional materials.

Helvajian believes glass-ceramic materials — glass that can be controllably converted into ceramic form after “shaping” — offer several promising advantages. They can be manufactured in a wide range of sizes; there are several cost-effective processing techniques available; the material’s strength can be tailored; it is lighter than most metals, and is easily adaptable to photonics and electronics mounted on ceramic substrates. However, the materials are difficult to micromachine cost-effectively, since they break easily. To address this issue, Helvajian and his colleagues have developed a new technique that merges the advantages of ultraviolet direct laser write patterning and batch processing, enabling them to make three-dimensional structures without having to employ the multiple “masks” used in conventional micromachining. The etch rate is much faster, enabling large area processing, and the user can vary the laser exposure dose during and selectively alter the chemical etch rate. The FEL is particularly useful for this application because it is tunable; the new technique uses sequential multiple wavelength exposure processing to create complex volumetric patterns.

According to Richard Haglund, a Professor of Physics at Vanderbilt University, FELs, with their unique combination of high-peak power, high-average power and broad tunability, offer new routes to the processing of materials under non-equilibrium, as well as a possible new paradigm for laser processing of complex materials. “Many organic and inorganic materials have rich vibrational spectra in the 1-10 micron (mid-infrared) region,” he said. “Tuning the wavelength means being able to control the density of vibrational excitation in the absorption zone, while changing wavelength may open chemically or thermally selective pathways for laser energy.” In comparison, solid state lasers still have limited tuning range and intensity, while fixed frequency IR lasers are unable to cover many vibrational bands.

Haglund described recent experiments in which thin polymer films of interest for electronic, biosensor, and drug delivery applications are made by pulsed laser evaporation under conditions of high local vibrational excitation, using the Jefferson FEL. The experiments demonstrated that efficient laser processing is possible at very high pulse repetition frequencies in metals as well as dielectric materials, and that resonant infrared excitation on the picosecond time scale produces a mode-specific response in dielectrics and polymers. While FELs proved to be quite efficient for this application, it is an open question whether they can be a compact user-friendly tool, particularly against the primary competing technology: tunable ultrafast solid state lasers.

Robert Austin, a Professor of Physics at Princeton University, concluded the session with a discussion of a series of biological experiments spanning the wavelength range from the near-visible to the far-infrared, conducted with FELs not only at Jefferson Lab, but also in Santa Barbara and the FELIX facility in Holland. These experiments have probed the picosecond time response of biological molecules to high levels of vibrational excitation in an attempt to discover how chemical energy moves through a molecule from the initial excitation. Based on this work, Austin drew several inferences about how future FEL developments could further advance the field.

For example, “To really probe the x-ray structures of proteins, we need single picosecond pulses,” he said, which Jefferson’s upgraded FEL facility will be able to provide. In addition, biological samples are fragile, and highly sensitive to harmonic and temperature variations, as well as magnetic fields. Austin’s group has made a microfabricated cell sorter through the deposition of magnetic films. Other potential biological uses include nanoimprinting for molecular fractionization, especially of DNA, a technique that is much cheaper at large scales than expensive electron-beam lithography. FEL light could also be used to snip genomes, and to precisely analyze the position of transcription factor proteins on genomes The latter application would use near-field mid-infrared pulses to cut DNA molecules locally at the same position where a transcription factor protein is located, merely by tuning the FEL to unique protein absorbence bands.

> ***The ultimate goal of Jefferson Lab’s FEL facility is to move beyond the constraints and limitations that prevent conventional lasers from providing the full benefits of coherent monochromatic laser light. Applications opportunities will continue to expand for users of the upgraded FEL.***

Laboratory Tours

Following the theme session lectures, conference participants toured Jefferson Lab. Stops included (1) the Jefferson Lab FEL User Facility, (2) the Applied Research Center, where scientists conduct research in plasma source/ion implantation, femtosecond lasers, and biomedical imaging, among other areas, (3) Continuous Electron Beam Accelerator Facility, and (4) the Test Lab, where accelerator components are designed and constructed. Participants were able to see firsthand the superconducting radio frequency components being made for both Jefferson Lab instruments and the Spallation Neutron Source currently under construction at Oak Ridge National Laboratory. The day closed with a reception and banquet at the Mariner’s Museum, where guests viewed artifacts from the USS Monitor and other maritime treasures. After the banquet, popular science author Lawrence Krauss received the AIP Award for Science Writing by a Scientist for his book, *Atom: An Odyssey from the Big Bang to Life on Earth... and Beyond*, and John Hightower, president and CEO of the museum, lectured on the museum’s salvage and preservation of the USS Monitor.

Policy Session: Science in a Security-Conscious World

Presidential Science Advisor Jack Marburger led off the session discussing of the role of science in a security-conscious world, beginning with the serendipitous emergence of nuclear weapons during World War II. This success became a paradigm for postwar arguments favoring public support for scientific research, since the course of the war was so strongly affected by such technological advances as nuclear weapons, radar, penicillin, and other areas of chemistry, optics and electronics. However, while security in the post-war period generally focused on nuclear weapons, it is no longer very useful for guidance in how to manage science in a security-conscious 21st century. Nuclear weapons technology remains highlighly classified, but "None of these precedents for dealing with security-sensitive technical material gives adequate guidance for the field of bio-warfare of bio-terrorism," said Marburger. While the technology to unravel molecular codes and structures is relatively difficult to acquire, it is comparatively easy to acquire knowledge of the technical procedures used to produce novel organisms for applications, which has implications for any policy aimed at enhancing national security against bio-terrorism.

According to Marburger, the most efficient means of preventing bioterrorism would be to classify the basic data that is difficult to acquire. However, this would have a deleterious impact on the development of all applications of biological research and generally impair the progress of the field. The policy currently in effect is the Reagan-era National Security Decision Directive 189, which states that to the maximum extent possible, fundamental research results should remain unrestricted, and that the appropriate mechanism for controlling information produced by federally-funded research is the classification process. While the Bush Administration issued a directive in March 2002 ordering federal departments and agencies to take steps to protect information regarding weapons of mass destruction and other information that could compromise national security, Marburger described the action as "a reasonable caution to agencies that generate and use such information; it does not signal an intent by the U.S. government to intervene in the process of review and publication of the results of scientific research."

Marburger also discussed federal policies calling for the tracking of foreign students and their fields of study, particularly through the development of an Interagency Panel on Advanced Science and Security (IPASS). The panel will evaluate the individual's background and previous education and training, their country of origin or affiliation, their scientific field of study, training or research, and the nature of the work currently conducted at the U.S. educational institution. Marburger emphasized that IPASS will work closely with educational institutions and scientific societies to determine what sensitive scientific knowledge is emerging, and that the panel's work will be monitored to ensure that the federal government maintains a healthy balance between scientific openness and homeland security. "We don't wish to turn away scientists unnecessarily," he said.

> ***A new paradigm is needed for managing science in an increasingly security-conscious world where bio-terrorism has replaced nuclear weapons as a prevailing threat. Any such policy must strive to balance security concerns with free exchange of scientific information, as well as the need to foster and support international students.***

James Fallows, national correspondent for *The Atlantic Monthly*, discussed a 1989 article in the *Marine Corps Quarterly* that proved to be eerily prescient in its prediction that the 21st century would be defined by what its authors termed "fourth generation warfare," meaning "war against enemies who refuse to fight fair," said Fallows. "They do not engage your military or a state apparatus, they find wherever you are weakest and they attack you there." Such enemies attack the population directly, and since they are not affiliated with a specific state, it is nearly impossible to retaliate. Thus, the tools we have used historically against national security threats are no longer viable, at a time when the U.S. is facing its greatest challenges in this area. "It is simply impossible to guarantee complete security of the nation; we live with the knowledge of certain vulnerability," said Fallows, pointing to the airlines, trucking systems, bridges, subways, postal service and food network, all of which are vulnerable to terrorist attack.

Furthermore, because these vulnerabilities exist and are not absolutely defendable, every security measure we consider becomes a matter of tradeoffs: strategic and legal tradeoffs, such as invoking martial law; cultural tradeoffs through constraints on the free flow of information and scientific exchange; economic tradeoffs, balancing extra security measures against efficient and profitable operation of business's, such as the airlines; and risk tradeoffs, such as implementing a nation-wide vaccination program against smallpox. The best bargains in terms of tradeoffs can be found in failsafe security systems, according to Fallows, and in general, distributed systems are more failsafe than centralized systems. "The Internet is a classic example of the robust distributed system," he said. "There's no central node through which everything passes, and thus there's no way to bring the whole thing down. The difficulty with centralized systems is that they are as vulnerable as their weakest link."

The airlines are a prime example of a centralized system, operating on a hub-and-spoke model that is highly vulnerable. "When something goes wrong in any part of the system, it ripples through the entire network," said Fallows. "That's why a storm in Denver can cause your flight to be delayed in Atlanta." It is his contention that the current airline system, with its heavy superstructure and centralized system model, "cannot be defended in its current form," and he predicts that this untenable situation will ultimately drive several airlines into bankruptcy. A potential alternative model transportation system is the development of a distributed "air taxi" service, based on the concept of private business jets. Especially after September 11, the market for charter jets has mushroomed. While there is a lack of central control, there is a robust local level of security, and the smaller planes can do less potential damage.

> ***Warfare in the 21st century will be defined by enemies who are not affiliated with a particular state, and who will attack civilian rather than military targets. Science can help identify where we can make useful tradeoffs to reduce our vulnerabilities by implementing distributed rather than centralized systems.***

Jane Alexander, director of science and technology at the Office of Naval Research (ONR), described that agency's efforts to develop technologies that will give the U.S. a strategic edge against so-called "asymmetric threats" that undermine both trust and the ability to conduct our day-to-day lives. The elements of security from the naval perspective are detection, control, and engagement, all of which must be done quickly and in layers, and at an affordable cost. ONR has implemented a new approach called "Sea Power 21," which provides a road map for naval development and transformation by focusing on power and access from the sea. The focus is on integrated, use-inspired research for eventual application to in-field force protection and port security, particularly for fixed installations. “We have some very large, expensive platforms out at sea, which makes them attractive targets (for terrorists),” said Alexander, pointing to air craft carriers, which cost over $2 billion apiece.

For example, ONR funds basic research on the physics of waves, with an eye towards application in computer wave modeling and prediction. The agency is also engaged in advanced technological development, such as autonomous underwater vehicles (AUVs); enhanced shipboard damage control through automated systems; organic mine counter measures; warfighter protection, such as the development of handheld ultrasound devices for combat casualty care and management; and the detection of explosives, particularly with emerging techniques such as nuclear quadrupole resonance, which depends upon the contrast in nitrogen concentrations between the explosive and the soil for detection. “Most detection of landmines and other explosive devices is done with metal detectors,” said Alexander. “But there is less and less metal being used in these devices. We really need to detect the explosive itself.” Better sensor technology to enable time-sensitive strikes is also needed. Finally, the ONR is striving to integrate these various components into a cohesive system.

Biosurveillance remains a difficult technical challenge, broad in terms of geography, scenario, and prospective targets. Jill Trewhella, bioscience division director at Los Alamos National Laboratory, reported that microbial agents replicate and evolve quickly, and enjoy a diverse and changing host range, which accounts for their popularity with criminal, terrorist and warfare factions. There is limited response experience to such attacks, and attacks are case sensitive; no two scenarios are exactly alike. Biotechnology follows a very nonlinear development path, and hence, technological surprises have a low probability but high impact, in instilling fear and panic in the population. Furthermore, attacks must be detected against a complex background of naturally emerging infections, such as the Spanish flu epidemic of 1918, which killed more than 20 million people worldwide. “We tend to think of biothreats as very much a human issue, but in fact, nature is the greatest bio-terrorist of all,” she said.

According to Trewhella, DNA-based microbial analysis is one of the most powerful existing tools in the fight against bioterrorism because it can rapidly identify known threat agents. With additional time, scientists can use genetic analysis to identify unknown microbes and pathogens, as well as detect genetic engineering and antibiotic resistance, which are important for response as well as attribution of the attacks. The establishment of databases showing the genetic relationships between the various microbes will help with DNA strain identification to determine the source of anthrax, or the presence of genetic engineering. For example, in the 1979 anthrax outbreak in Russia, researchers identified multiple strains of anthrax in the 11 victims, which strongly suggested intentional mixing. “Multiple strains could be a devastating weapon, because it makes the selection of therapy problematic, especially when combined with multiple drug or vaccine resistance,” she said.

DNA signature development requires production-scale, high-throughput analysis, and there is a national pathogen sequencing program to support this effort by mapping microbial family trees. In addition, real time sensors are needed, which will mostly likely be based on novel nanobiomaterials. We have limited capabilities for identifying pathogens immediately after release, which hinders response, and no practical capability for pre-symptomatic identification, which is critical to saving the lives of those exposed to lethal biological agents. Finally, developing a strong biosurveillance infrastructure requires a massive public health investment, similar in scale to the fight against cancer and HIV. “For the foreseeable future, we are in “chase” mode,” Trewhella concluded. “That’s why we need to look at the full spectrum of intervention capability, not just technologies, but also things like export controls, treaties and protocols.”

> ***Bioterrorism is a ubiquitous and eternal threat. Translational research to bring basic science ideas into real-time devices that can be put into the hands of users in the field is absolutely critical to addressing the threat from biological agents.***

Frontiers in Physics Session

“Atomtronics” is the buzzword for an emerging technology where cold neutral atoms are manipulated on or near an atom chip, similar to the way in which electrons are used in electronics and photonics, using atom-based analogs of mirrors, lenses, waveguides, gratings and other devices. The field is also potentially useful for the realization of quantum computing. Theodor Hänsch, director of the Max Planck Institute for Quantum Optics in Germany, is one of the growing number of researchers worldwide striving to create atom optic devices on a chip, such as atom lasers and interferometers. The current workhorse for manipulating cold atoms is the magneto-optical trap (MOT), whether it be a classical gas or a Bose-Einstein Condensate (BEC), and the technology has advanced to the point where scientists can construct MOTs directly onto a microchip.

Atom chips integrate traps, waveguides, beam splitters and the like onto a single chip to form complex systems. For example, in 2001 Hänsch’s group was able to confine atom clouds in separate potential wells and precisely transport them near a surface with time-dependent currents in a lithographically patterned conductor. “We’re basically using atomic potential wells for transport, essentially sending smoke signals with cold atoms,” said Hänsch. They have used their “magnetic conveyor belt” to merge separate clouds, and to demonstrate that the process can be reversed to coherently split wavepackets. The group has also built a multi-layer atom motor by splitting and merging trapped atom clouds, which are a key element for the construction of laser atom interferometers, and can also make small permanent magnetic structures by “writing” them into magneto-optical films. The ultimate goal is to create a quantum lab on a chip, using atom chips as a quantum processor, which would require, among other technological advances, the ability to prepare and read out single atoms.

A somewhat related area is “molecular electronics”: the exploitation of molecular assemblies for a plethora of electronics and optoelectronics applications. For example, individual molecules acting as wires and switches offer a promising avenue for the achievement of integrated circuit chips tightly packed with electronic devices. Mark Reed and his colleagues at Yale University have fabricated molecular wires and measured electric conductivity directly through a small number of molecules, and in 2001 they demonstrated that bundles of several thousand of these molecules could be fashioned into functioning random-access-memory devices. Specifically, Reed demonstrated that the tiny circuits can be switched controllably between conductivity states in such a way that data can be written, read and erased from the bundles.

Reed is also a co-founder of Molecular Electronics Corporation, and his research provides part of the basis for two necessary components of molecular electronics: a molecular switch and a molecular memory, while other researchers associated with the company have collaborated to construct and test molecular wires. Taken together, these technologies would provide the necessary components for a nanometer-scale logic circuit. MEC's technologies use inexpensive chemical processes to synthesize and arrange molecules using self-assembly, and the resulting systems have been shown to demonstrate logic switch behavior, memory behavior and pathways for the transmission of electrons, with similar performance to some current silicon-based semiconductors. In fact, according to Reed, the process for manufacturing molecular electronics devices is likely to be more akin to developing photographic film than the lithographic and mechanical processed used today for making silicon chips.

Despite the rapid advances in laser technology, until quite recently is has not been possible to generate laser-like beams of x-rays from a simple device. Working with colleagues at the University of Colorado/JILA, Margaret Murnane has made significant progress towards that goal by converting extremely intense light pulses into laser-like beams of x-rays. In imaging, the smallest structure that can be seen is about the size of the wavelength used, so femtosecond x-ray pulses have the potential to probe very small structures as they evolve. Thus, these femtosecond pulses of light are extremely useful scientific tools because they can used to freeze the motion of fast-moving events, similar to a strobe light or camera flash, making it possible to observe some of the fastest processes in nature, such as the making and breaking of molecular bonds, DNA replicating at the molecular level, catalysis at surfaces, the motion of electrons in circuits, or even the processes that occur in living cells.

In 2001, Murnane and her colleagues generated a new and flexible approach to working with laser light in the world of ultrafast science by successfully combining extremely short pulses of light generated by two independent lasers into a single pulse of light that exhibits the properties of both lasers simultaneously, creating new shapes of light pulses that could not be created by either laser individually. Being able to combine the characteristics of two or more pulsed lasers working at different colors (or wavelengths) will give scientists a more flexible approach to freeze the motion of events in atoms and molecules to learn more about light and matter.

For the past 50 years, electron optics engineers have sought to improve the precision of electron microscopes by counteracting the image-blurring effects of lens imperfections, called "aberrations." Philip Batson, a research scientist at IBM, has been involved in aberration correction in scanning transmission electron microscopes (STEMs), helping to demonstrate a sub-Angstrom beam size at 120 kV for the first time. "We are now seeing the first instruments that are able to resolve details at twenty times the imaging electron wavelength," he said. This means it is now possible to image the silicon lattice with atomic resolution, and the smaller probe size in the STEM increases the contrast available for the imaging of small numbers of atoms. For example, single atoms of gold on a thin carbon substrate can be imaged at video rates, enabling the exploration of the room temperature motion of atoms.

The largest imperfection, a “spherical aberration,” cannot be fixed in a single lens. Batson and his cohorts combined seven new sets of magnetic lenses with modern computers to actively correct the aberration in real time, resulting in a microscope capable of producing an electron beam that is only 75 thousandths of a nanometer, smaller than a single hydrogen atom. Using this correction technique, scientists can now observe defects in semiconductor materials such as missing or extra atoms, and find ways to repair them. “We can’t fix what we can’t see,” said Batson. “And as the dimensions of computer chips continue to shrink, scientists need new tools to explore the structures and properties of materials used in these chips.” The breakthrough improves scientists’ ability to see and thoroughly explore properties of electronic materials, and may one day lead to a better understanding of how to control environmental conditions such that future components of computer chips could be self-assembled.

> ***The Frontiers in Physics session aptly demonstrated how innovative new tools and materials lead to potentially revolutionary advances in both fundamental science and industrial applications.***

Agilent Technologies will host the 2003 Industrial Physics Forum, *Physics in the Life Sciences*. October 26-28, 2003; San Jose, CA.