Photon STM Extends Optical Imaging Resolution

Researchers at the Tokyo Institute of Technology say they are well on the way to realizing the "ultimate" optical microscope, a very high-resolution photon scanning tunneling microscope (PSTM). Last year (see the June 1991 *MRS Bulletin*, p. 8, and the March 22 issue of *Science*), researchers at AT&T Bell Laboratories reported the development of an optical microscope (which they called the near-field scanning optical microscope) with resolution extending beyond the diffraction barrier, attaining ∿12 nm. According to team leader Motoichi Ohtsu, the Tokyo Institute's device goes even farther, with a resolution of 5 nm. Ohtsu's device can also capture individual atoms and move them to designated places on a substrate.

In the PSTM, a specially crafted optical fiber passes over an illuminated sample while picking up surface evanescent waves. Its power varies exponentially with the distance of the probe from the surface. To obtain the desired effect, the separation between the sample and probe must be smaller than the optical wavelength of the illuminating light, about one micron. "By operating at such a very small distance, we can neglect the wave nature of light and, thus, diffraction," said Ohtsu.

The device's resolution centers on its scanning tip; a sharper tip can achieve better resolution. "If we use a very small aperture, much smaller than the wavelength, the resolution is completely limited by the diameter. Then, if we scan the surface of a sample, a kind of three-dimensional image is obtained," Ohtsu said. Although the resolution of a conventional optical microscope is about the wavelength of light, in this case the resolution is limited only by the aperture fabricated at the top of the fiber. Ohtsu said that their tip is 4-5 times smaller than others now available, with a radius of curvature less than 5 nm. Its cone angle is 20 deg. This sharpness was attained by chemical etching. In addition to having a sharp tip, the specially modified AlGaAs laser is particularly stable, Ohtsu said, and the system is compact. Measurement times can be very small, and the laser's coherence is about 10^5 better than conventional Japanese diode lasers. The team achieved a linewidth of 7 Hz.

The researchers say they have been able to investigate biological samples, including bacterial phage T4, in the atmosphere at a resolution approaching that of a SEM, which generally requires coating the sample with metal and a very high vacuum.

The transmission-type PSTM can also be used as an "optical tweezer" to trap and manipulate single atoms, Ohtsu said. "In this case the laser power is irradiated, and an evanescent wave is generated around the aperture; this evanescent wave has power, a force, which can push or pull the atom. If an atom is impinged and jumps into this evanescent wave, the atom is trapped by the force of the photons." As long as the lasing frequency is fixed to the appropriate frequency, they can hold and move the atom as desired. "Since our laser frequency is very stable, we can fix the laser frequency to be slightly higher or lower than the atomic resonance frequency," Ohtsu said.

They can thus pick up an atom and carry it to a cold crystal surface; by changing the laser frequency the atom is pushed out and deposited on the cold substrate. Ohtsu calls the PSTM a single-atom-level crystal-growing machine.

Much engineering is needed to improve reliability and reproducibility and Ohtsu expects that the PSTM will take two or three years to reach the market. However, the researchers have a contract with Nikon. The company is also working on an atomic force scanning microscope that relies on van der Waals interactions between two atoms.

Ohtsu said the STM, the atomic force microscope, and the PSTM can be explained by a unified model. He does not use wave optics, which he says are too complicated for this case, but uses the simpler photon model. "For the unified model, we are using Feynman diagrams. Using this model, we can compare the classical model with the conventional electron microscope and our photon STM," he said.

In addition to this transmission-type PSTM, in which light is transmitted through the sample, Ohtsu has also proposed a resonance-reflection-type PSTM that uses a very small Fabry-Perot resonator. If the FP cavity is irradiated by a laser, the evanescent lightwave leaks from the aperture. If the sample is placed very close to the aperture, the resonance frequency of the FP resonantor varies slightly. However, because the laser frequency is locked to the resonantor frequency using a servo frequency control, changes in the resonant frequency are transferred to the change in the lasing frequency, so even very small changes are detectable.

"The secret to detecting very slight change in the resonant frequency," said Ohtsu, "is a very stable laser; with our laser system we can detect frequency changes as small as 0.4 millihertz, eventhough the optical frequency is 100 terahertz; thus the accuracy is as high as 10^{-18}." This was achieved by modifying the frequency control electronics circuit.

F.S. Myers

Forced Vapor-Phase Fabrication Speeds Production of Tough Ceramics Composites

The ceramic surface systems group at Oak Ridge National Laboratories has developed a process that encapsulates long threadlike ceramic filaments in brittle ceramics to provide more crack resistance.

Conventionally, ceramic powders are pressed into shape under tremendous pressure, then fired in a furnace. But this process breaks down the continuous filaments, destroying their ability to prevent the penetration of cracks. Chemical vapor-phase infiltration, in which hot gases were used to coat a ceramic-fiber preform, overcame these problems, but the process was tedious and expensive.

But forcing the matrix-forming gases through the preform speeds the process and reduces the cost. Instead of taking one month to produce a one-eighth-inch part, it now takes 24 hours to produce a one-half-inch part. An additional benefit, said Ted Besmann, head of Oak Ridge's ceramic surface systems group, is that the process is self-optimizing. The forced gases can't go through the dense sections of the part, so they go to the less dense areas, which is exactly where more ceramic material needs to be deposited.

The continuous-filament ceramic parts have already been used in French Mirage jet thrust deflectors, jet combustion chamber liners, and rocket nozzles. Researchers say there is a growing interest in using them for aerospace applications, heat exchangers, recuperators, and fluidized combustors.

The Oak Ridge team is using mathematical modeling so that they can scale up for bigger parts and new furnace systems. The group is also looking at materials that might perform better in corrosive atmospheres than the standard silicon carbide material and at ways to better interface the threads in the preform with the matrix coating.

Allied-Signal, Argonne Study Silicon Nitride Toughness Under CRADA

Resistance of the ceramic silicon nitride to fracture and erosion will be studied under a cooperative research and development agreement (CRADA) announced by Allied-Signal, Inc., and Argonne National Laboratory. Silicon nitride is considered a leading candidate for uses in high-efficiency, high-temperature ceramic engines.

The one-year, $100,000 agreement will fo-

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cus on understanding how cracks originate and grow through silicon nitride under stress or erosive conditions and how these properties are affected by fabrication techniques. Each organization will contribute $50,000 in effort and materials.

Researchers Grow 5 mm Zeolite Crystals

University of Illinois chemist Walter G. Klemperer and colleagues have developed a method for consistently growing zeolite crystals up to 5 mm across, hundreds of times larger than ordinary zeolites and more than five times larger than the largest previously grown. This size will permit better experiments to understand their extremely complicated structures, which can enclose the equivalent of 100,000 holding pens in a space no longer than 0.1 mm.

Zeolites are tiny inorganic crystals, naturally permeated by hundreds of thousands of channels or chambers. The channels allow materials, such as molecules of gasoline or unsoftened water, to pass through them. The crystal walls of the zeolites or the molecules within them can act as catalysts to modify molecules passing through. Zeolites can also be used as sieves to remove radioactive cesium or strontium from contaminated water.

Klemperer's group has produced zeolites perforated with chambers that hold atoms rather than allowing them to pass through, making possible the study of molecules organized in three dimensions by the crystal.

The structure of the giant zeolites is determined by organic molecules that serve as a template for the crystal as it grows. A gold wire is wrapped around a seed crystal and hung in a container in which more crystalline materials and organic molecules in solution bathe the crystal. The container is heated under pressure and the growing process takes three to five days. Crystal properties are changed by distortions of the crystal's chambers. A crystal in which the chambers were distorted in the same direction would produce harmonics, or multiples, of laser light frequencies, a phenomenon with important implications in optoelectronic communication.

ONR Seeks Interdisciplinary Research on Marine Bioadhesion Intervention

The Office of Naval Research (ONR) recently announced opportunities for research funding in the Molecular Interactions at Marine Interfaces Program. The program "seeks to support innovative research that will elucidate the chemical and physical principles governing bioadhesion mediated through interfacial interactions of biologically-produced exopolymers and model polymers surfaces." The goal is to use "the basic principles which result in the design of generic means of intervention." The multidisciplinary program involves molecular biology, biochemistry, organic chemistry, and polymer chemistry. The program will last approximately five years and employ around 20 researchers.

For further information, contact: Randall Alberte (molecular biology), (703) 696-4039; Harold Guard (organic chemistry), (703) 696-4311; Michael Marron (molecular biology), (703) 696-4038; or Kenneth Wynne (polymer chemistry), (703) 696-4315.

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DOE Announces 10-Year, $100 Million Ceramics Research Program

In a move to improve the efficiency and productivity of industrial manufacturing processes, the U.S. Department of Energy announced a new 10-year, $10 million program to work with 10 research teams, involving 35 companies, universities, and national laboratories, to develop continuous fiber ceramic composites (CFCCs).

Citing a need for lighter, stronger, more corrosion resistant, high-temperature resistant materials, DOE officials believe the successful development of ceramic composites would positively affect U.S. competitiveness, job creation, and industrial energy efficiency. Industrial applications for the CFCC program range from heat exchangers to critical components for high-temperature gas turbine engines. The potential for annual energy savings could run in the billions of dollars.

The 10 industry teams will receive $7.6 million in Phase One contracts, which will last from 15 to 24 months. The 10 industry team leaders are Allied-Signal Inc., Alzeta Corp., Amercom Inc., Babcock & Wilcox, Dow Chemical Co., Dow Corning Corp., Dupont-Lanxide Composites Inc., E.I. du Pont de Nemours & Co., General Electric Corp., and Textron Specialty Materials.

Jorgensen Wins DOE Materials Research Competition

James Jorgensen of Argonne National Laboratory has won the Department of Energy's Materials Science Research Competition for sustained outstanding research in solid-state physics. His extensive work in the field of powder diffraction at pulsed neutron sources was recognized by DOE's Office of Basic Energy Sciences (BES).

Jorgensen, a senior physicist and group leader at Argonne's Materials Science Division, has received several other awards for his work, including the American Crystallographic Association's Bertram E. Warren Diffraction Physics Award in 1991 for developing neutron powder diffraction techniques at pulsed neutron sources. He also shared DOE's 1991 Materials Science Research Competition Award for Outstanding Scientific Accomplishments in Solid State Physics for neutron powder diffraction research on oxide superconductors.

Powder diffraction has been carried out at nuclear reactors, where as a byproduct, a steady stream of neutrons is produced. The BES award recognizes Jorgensen's development of instruments and data analysis techniques that allowed powder diffraction at other kinds of facilities, like Argonne's Intense Pulsed Neutron Source which generates neutrons in discrete bunches by bombarding a uranium target with a beam of protons.

T.J. Ahrens and J.D. Corbett Elected to NAS

The National Academy of Sciences (NAS) elected T.J. Ahrens of the California Institute of Technology and John D. Corbett of Iowa State University into membership along with 57 other U.S. researchers and 14 foreign associates. Ahrens is a professor of geophysics and Corbett is a pro-

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fessor of chemistry.

Election to NAS membership is considered one of the highest honors that can be accorded a U.S. scientist or engineer. Current total of active members is 1,651.

Penn State Chemists Find Metal-Carbon Multi-Cage Molecules

A team of Pennsylvania State University chemists have discovered that ball-shaped metallo-carbohedrene cages, formed by vaporizing the surface of a metal rod with a laser in a chamber of hydrocarbon gas, will join together to create interlocking, multi-ball clusters. The metallo-carbohedrene cages are formed when atomized material from the rod's surface links with the carbon atoms in the chamber's gas.

Made from 20 metal and carbon atoms, the metallo-carbohedrene molecule was originally discovered by Penn State chemists earlier this year. Now the team has found networks made from two, three, and four interlocking molecules, as reported in the May 8 issue of *Science*. "This unusual growth process is a tremendous surprise that suggests unique and useful electronic properties," said A. Welford Castleman Jr., chemistry professor and research team leader. "These identical cages give us a way of confining the various numbers of electrons in different metals, possibly providing a way to build materials with tailor-made electronic and catalytic properties," he said.

A few months ago, Castleman's team detected metallo-carbohedrene molecules with 8 titanium atoms and 12 carbon atoms that appeared to be arranged in 12 pentagon-shaped rings, forming a symmetrical hollow cage. "The shape of this molecule makes it unusually stable," said Castleman, explaining that once the atoms link up in this shape, it is difficult to break the bonds between them. The chemists soon found they could make the same shape with different metals, confirming that they had discovered a new class of stable molecules. "We thought our next discovery would be that this molecule comes in a range of sizes," Castleman said. Instead, they discovered the new "multiball" growth pattern.

By using rods made from various metals, the team has made metallo-carbohedrene molecules containing 12 carbon atoms linked with 8 atoms of titanium, vanadium, zirconium, or hafnium. "We wondered if we could use every transition metal to make these molecules," Castleman said, "so we tried tantalum, which has just one proton more than hafnium." The result was not a hollow metallo-carbohedrene cage, but a closely packed clump of cubes. "There are hints that there is something different in how these cages form when they contain titanium, vanadium, zirconium, hafnium, and possibly other transition metals," he said.

The chemists next will seek a way to make gram quantities of metallo-carbohedrene materials instead of just a few molecules.

Argonne Pursues Joint Superconductor Research

High-temperature superconductors made from powders melted while suspended in air will be studied under an agreement announced by Intersonics, Inc. and Argonne National Laboratory. Another joint research project between Argonne and Intermagnetics General Corporation (IGC) aims at manufacturing practical lengths of wire from high-temperature superconductors.

The nine-month, $150,000 Intersonics project seeks to determine which combination of raw materials and processing methods makes the superconductor with the most useful properties. Air-suspension of a material's particles could mitigate the problems of crucible processing in which small amounts of unwanted impurities might degrade a material's properties. Air melting could also increase the uniformity of a sample's crystal structure, allowing better electric flow.

The IGC project aims to produce wire about 10 yards long that can be shaped into coils for magnets and other uses. DOE will provide $1 million to support work at Argonne and $500,000 to support work at IGC, and IGC will contribute $500,000 of its own.

The groups will investigate which combination of powder and processing makes the best wire. A two-inch-long single-strand wire manufactured recently by IGC showed the highest current densities recorded in the United States for high-temperature superconductor wire. Researchers in Japan have reported similar values. The current density was 64,000 A/cm^2 when the wire was cooled to 4.2 K in a 20 T magnetic field. In the absence of an applied magnetic field, the same wire showed current densities of 164,000 A/cm^2 at 4.2 K and more than 30,000 A/cm^2 at 77 K.

University of Illinois Receives Grant to Study Nanolithography

A University of Illinois research group was awarded a five-year $4.3 million grant from the Department of Defense to build electronic devices on the scale of atoms. Researchers at the University's Beckman Institute for Advanced Science and Technology will seek ways to speed the development of yet smaller computer components using nanolithography.

The group's primary tool is a scanning-tunneling microscope (STM) that can detect individual atoms and also move them. The electric field at the tip of the probe can also trigger chemical reactions, opening the possibility for more complex pattering of circuits on a very small scale.

Problems to be overcome are how to view a relatively large area with the STM without losing fine resolution and how to move the scanning area without image degradation caused either by movement

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within the STM or by outside sources such as footsteps, nearby traffic, pipes, or wiring.

Industry will have immediate access to the research through an industrial affiliates program. Industry and government laboratory interactions will also shape the project's goals.

Seehra Appointed Eberly Distinguished Professor at WVU

Mohindar Seehra was named the Eberly Family Distinguished Professor of Physics at West Virginia University. The school's fourth Eberly professor, Seehra has been associated with WVU for nearly 23 years. His research has focused on the fundamental aspects of magnetic materials, phase transitions, and coal research, including causes of black lung disease. He also established a major research laboratory in experimental solid-state physics at WVU.

Seehra received his PhD degree in physics from the University of Rochester in 1969 and has published over 100 papers in refereed journals. He was selected as an Alfred P. Sloan Foundation Research Fellow, received externally funded research grants totaling over $2 million, and has presented numerous talks at universities and conferences. Seehra has also served as mentor for young faculty members as well as students and postdoctoral researchers.

Pirelli Receives Contract to Develop Superconducting Commercial Cable

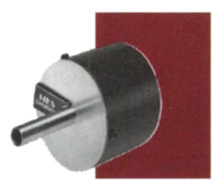
The Electric Power Research Institute (EPRI) awarded a research contract to Pirelli Cable Corporation to develop high-temperature superconducting cables for commercial power applications in cooperation with American Superconductor Corporation.

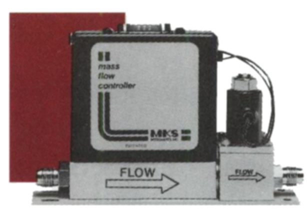
EPRI, the R&D representative for U.S. electric utilities, is providing the funding to Pirelli to accelerate the progress of newer power technology. Pirelli's strength lies in development, manufacturing, and marketing of cable, while American Superconductor possesses proprietary processes for developing high-temperature superconductors. The two firms have worked together for three years.

Smalley Among E.O. Lawrence Award Recipients

Richard E. Smalley, physical chemist at Rice University, along with five other researchers, received the Department of Energy's Ernest Orlando Lawrence Memorial Award. Smalley received the award for research and leadership in the generation and characterization of atomic clusters and, in particular, for the discovery of the C_{60} buckminsterfullerene and its related compounds. The award, which honors the memory of the late Ernest Orlando Lawrence, inventor of the cyclotron, is given to U.S. citizens who are relatively early in their careers and who have made recent meritorious contributions to areas relating to the development, use, or control of atomic energy.

The other recipients are Zachary Fisk, Los Alamos National Laboratory; Richard Fortner, Lawrence Livermore National Laboratory; Rulon Lindord, Los Alamos National Laboratory; Peter Schultz, Lawrence Berkeley Laboratory; and Pace VanDevender, Sandia National Laboratories. □





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NSF Program Solicitations

Materials Research Groups Program ▪ Announcement NSF 92-43
Provides support for collaborative, multi-investigator efforts that address major problem areas in materials research; instrumentation support also provided. Areas include condensed matter physics, materials theory, solid-state chemistry and polymers, metallurgy, ceramics, and electronic materials. **Deadline is August 28, 1992**

Materials Research Laboratories Program ▪ Announcement NSF 92-44
Funding for interdisciplinary materials research at qualified universities. Essential activities include but are not limited to major research programs where sustained, cooperative effort by several investigators with diverse backgrounds is needed; development, operation and maintenance of central research facilities; and seed funding for new initiatives and investigators, and novel concepts in materials research. **Deadline is October 2, 1992**

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