STM Manipulates Si Atom Clusters

Using a scanning tunneling microscope (STM) at room temperature, IBM scientists have shown that small clusters of silicon atoms, or even individual atoms, can be lifted from a silicon substrate and deposited elsewhere.

The findings, presented in the July 12 issue of *Science* by In-Whan Lyo and Phaedon Avouris of IBM's T.J. Watson Research Center, describe how a voltage pulse applied at different distances from the silicon surface controls the force used to pull the atoms from the surface. By combining the effects of the strong electric field formed between the STM tip and the surface with chemical tip-sample interactions, Si atoms and Si clusters of up to tens of atoms can be transferred from the sample to the STM tip. These clusters or atoms can then be redeposited at another site on the surface.

The mechanism, a field evaporation process, uses a low-threshold field modified by chemical and mechanical tip-sample interactions, the scientists report. Field evaporation involves the ionization and desorption of individual atoms or clusters of atoms from the surface of a material by the application of a strong electric field.

In the STM, large electric fields can develop between the tip and the surface sites under the tip. The field intensity can be varied either by applying variable voltage pulses at a fixed tip-sample separation or by applying the same voltage pulse but varying the tip-sample distance. Additionally, chemical interactions occur when the tip is very near the sample.

An electric field of 1 V/Å was enough to cause the silicon atoms below the tip to form a small mound. As the field was increased by moving the tip closer to the sample, the first Si atom layer was removed. Individual atoms were removed by using a lower voltage at a closer distance. Single-atom desorption was less reproducible than cluster desorption because it critically depends on the tip sharpness.

A voltage of +3 V cleanly transferred the entire mound of silicon to the STM tip. The STM can then be used to deposit the Si atoms anywhere on the surface by moving the tip and applying a voltage pulse of -3 V.

This field-induced process provides a powerful tool for the nanometer-scale processing of strongly bound materials and could be used to build semiconductor structures, produce and deposit clusters for study by scanning tunneling spectroscopy and other techniques, or generate local doping schemes.

Peppas Receives Controlled Release Society Award

Pharmaceutical researcher and chemical engineer Nicholas A. Peppas is the 1991 recipient of the Founders Award for Outstanding Research from the Controlled Release Society. The award is offered to "scientists who have made exceptional contributions to the science and technology of controlled release." Peppas received the honor during the 18th International

Symposium on Controlled Release of Bioactive Materials in Amsterdam this July.

Professor of chemical engineering at Purdue University, Peppas also teaches courses on controlled released at the Massachusetts Institute of Technology, where he received his ScD. He has authored numerous publications, including the books, *Biomaterials* and *Hydrogels in Medicine and Pharmacy*, and is on the editorial boards of several biomaterials journals. Peppas has served in a number of professional associations and was 1989-90 chairman of the Materials Division of the American Institute of Chemical Engineers. Recently, he was elected a Fellow of the American Association of Pharmaceutical Scientists.

IR Microprofiling Locates and Identifies Surface Contaminants

Infrared (IR) microprofiling, a technique that combines IR microspectroscopy with a precise, scanning movement of the microscope stage, could prove particularly useful in identifying and locating certain types of surface contaminants. The technique, developed at Sandia National Laboratories, can be used to locate and chemically identify samples as small as 10 μm in diameter with an accuracy of 1 μm. Potential applications exist in the semiconductor industry, nondestructive failure analysis, and forensic medicine.

IR microprofiling, an extension of IR spectroscopy, provides information about molecular structure by determining the frequency and intensity of light a compound absorbs in the infrared region. The resultant IR absorption spectrum is characteristic of the compound. Like traditional IR microspectroscopy, IR microprofiling can be used to examine contaminants present in the form of particles, droplets, smears, fibers, crystals, inclusions, bubbles, or additives. While the IR microscope and motorized stage drive have been commercially available, the technique was made useful for contaminant identification by modifying existing software used for other IR techniques to allow researchers to organize the tremendous amount of data produced.

A data reduction technique used in gas chromatography/Fourier-transform infrared spectroscopy reduces the spectra acquired at each pixel element to a single value. This value is representative of the type and quantity of the contaminant. Plotting these values as a function of pixel position results in a three-dimensional projection.

While data collection time can be long with this technique, the hands-on time of the spectroscopist is minimal because both the IR data collection and motorized stage drive are fully automated.

Microwave Processing to be Used for Ceramic Engine Components

Microwave processing facilities at Oak Ridge National Laboratory will be used to help Garrett Ceramic Components (a division of Allied-Signal Aerospace Company) develop ceramic heat engine components with improved strength and toughness.

Garrett will have direct access to Oak Ridge's microwave processing equipment and expertise for evaluation of microwave processing for specific ceramic components. Oak Ridge will have access to commercially produced ceramics for annealing studies, and to conventionally prepared test parts made by Garrett of the same chemical compositions for comparison purposes. The cooperation is geared toward demonstrating technology for fabricating heat engine components at relatively low cost via microwave processing.

The work is expected to take about six months.

Self-Cleaning Tools Reduce Chip Contamination

Armed with evidence that particles generated inside tools during the manufacture of semiconductor chips can be the major cause of contamination rather than cleanroom particles, IBM scientists have developed a way to control contamination by self-cleaning tools.

Contamination in the form of microscopic particles occurs in plasma tools, widely used in chip manufacture, and interferes with the fabrication of integrated circuits, costing the semiconductor industry over a billion dollars per year worldwide. Attempts to reduce this loss have focused on improving the quality of the cleanrooms and the purity of the chemicals as well as frequent cleaning of the tools. But because particles are created in many different ways, ranging from chemical interactions to flaking from the chamber walls, total elimination of the contaminants is effectively impossible.

The scientists showed, however, that the contaminants could be controlled by a relatively inexpensive design modification that deflects the tool particles away from the wafers. The design change takes advantage of the tool's electrical effects.

During normal operation, the silicon wafers rest on a sample stage that serves both as a support and as an electrode. The wafers are separated from a second parallel electrode by a gap. When a radio-frequency current is applied to the support electrode, it ionizes the processing chemicals in the chamber, creating a plasma in the gap. The contaminants acquire a negative charge from the plasma and remain electrostatically suspended during normal processing, allowing them to drift over the wafers. By cutting grooves in the electrode, the scientists channeled the hovering particles into an electrical "drain pipe," avoiding the wafer and pumping them out of the chamber.

Plasma tools are among the dirtiest used in semiconductor fabrication, and the ability to control contaminants through self-cleaning tools could significantly reduce contamination levels in the manufacturing line. Also, the trend toward clustered tooling, in which wafers remain in a vacuum as they are sent from one processing chamber to another and therefore have no opportunity for wet cleaning, provides an even stronger motivation for the use of self-cleaning tools.

Work on the self-cleaning tools was carried out by Gary S. Selwyn and John E. Heidenreich of the IBM T.J. Watson Research Center, and Kurt L. Haller of the IBM General Technology Division semiconductor facility in Vermont.

Silicon Nitride Grating Makes Atoms Act Like Waves

Engineers working at Cornell University's National Nanofabrication Facility (NNF) have built a tiny silicon nitride grating so small that a single atom, in effect, flows through more than one space simultaneously before reassembling itself.

This behavior results from atoms' wave-like nature, described by quantum mechanics. Just as light waves can flow through several slits in a diffraction grating, waves of atoms can be made to behave in the same way if the grating is fine enough. The researchers have reported the development of "atom optic" gratings with slits 200 nm wide.

Both atom waves and light waves can exhibit interference, where diffracted waves can be made to recombine. In recombining, the waves cancel each other out at some points and reinforce each other at others, creating an interference pattern of light and dark.

Scientists at the Massachusetts Institute of Technology (MIT) have used the ultra-fine grating produced at NNF to build "atom interferometers" that demonstrate this phenomenon for streams of sodium atoms. These devices could provide fundamental insight into the nature of the atom and new tests of basic physical theories. The interferometers could also be used as extremely sensitive inertial navigation instruments, since the slightest change in direction would affect the flow of streaming atoms and change the interference pattern.

The tiny gratings were produced at NNF in a 10-step process using many of the tools of nanofabrication, including electron beams, ion beams, chemical etching, and photolithography. First, the engineers deposited a thin film of silicon nitride on a silicon wafer and used potassium hydroxide to etch a section of the silicon, leaving a thin membrane window of silicon nitride framed by the silicon. Then, the researchers covered the window with polymethyl methacrylate (PMMA) and used electron-beam lithography to create a grating pattern in the PMMA on the silicon nitride window. This pattern was basically a series of parallel slots, with the bare silicon nitride exposed only in the depths of the slots. Then the engineers bombarded the pattern with a beam of carbon tetrafluoride and hydrogen which selectively etched away the exposed silicon nitride, producing the precise slits. Engineers then dissolved away the PMMA, leaving the grating.

Asphalt Chemistry Model Cites Amphoterics

Researchers in Wyoming and Pennsylvania have learned that amphoterics, while constituting only 10-15% of asphalt, influence its tendency to form cracks, ruts, and potholes. (An amphoteric material can behave as either an acid or a base.) In asphalt, amphoterics appear to exert major control over the formation of molecular matrices. Although much of the new knowledge is a departure from the asphalt chemical model accepted for decades, investigations by the National Research Council's Strategic Highway Research Program (SHRP) have produced a great deal of new evidence in support of a new model.

Until now, little was known at the chemical level about how asphalt worked. Armed with the new understandings, it will be possible to make an asphalt that conforms to the needs of road builders. The properties of the network are very important for the final performance of the asphalt. If the network is not stiff enough, it will be prone to rutting. If it is too stiff, it may suffer from fatigue cracking. Moisture sensitivity, which may lead to cracks and potholes, is also a function of the network. It is the polar molecules that cause the asphalt to adhere to the aggregate, and it is this bond that breaks down in pavements suffering from moisture damage.

SHRP is developing tests that manufacturers can use to determine the chemical and physical properties of asphalt cement, enabling companies to modify the material for better performance. Another series of tests is being developed for use by highway agencies so they can select asphalt cements and aggregates that will give the best performance. New performance-based specifications for both asphalt binders and mixtures are based on these tests.

Gold Sulfite Offers Nonhazardous Deposition for Microelectronics

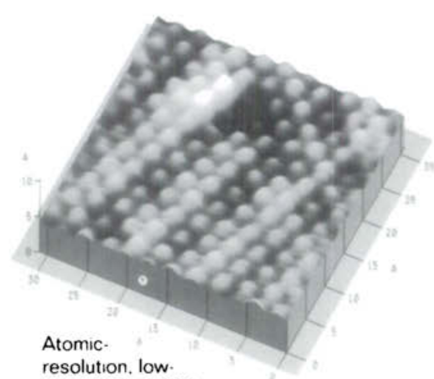
A gold sulfite electroplating solution originally developed in the 1970s has been refined to form the precise gold patterns required for semiconductor devices. The sulfite-based process offers an alternative to current, hazardous, cyanide-based gold plating solutions. The gold sulfite process has been limited to protective coverings, but researchers at Sandia National Laboratories have refined the sulfite solution to a plating efficiency of close to 100% with a density approaching that of pure gold. Gold plating of lines and spaces 2 μm wide and 4 μm thick on substrates has been demonstrated.

Researchers have also used the gold sulfite process to fabricate miniature gold bridges to form crossovers on gallium arsenide substrates. The crossovers allow conductors to cross on the surface of electronic devices without touching or electrically shorting out. Work continues to improve the technology to include a wider range of photoresists and increased precision for additional microelectronics applications.

Wynblatt to Head Carnegie Mellon's Metallurgy & Materials Department

Paul Wynblatt, professor of metallurgical engineering and materials science and associate dean of Carnegie Mellon University's engineering college, has been named head of the university's Metallurgical Engineering and Materials Science Department.

Wynblatt, who worked as a research metallurgist for the Israeli Atomic Energy Commission and in various research positions at Ford Motor Co., joined the Carnegie Mellon faculty in 1981. He became associate dean of the engineering school in 1989 where he was responsible for graduate student affairs and promotion and tenure. An expert in surface science, Wynblatt



has focused his research on the interfaces of materials. He has published nearly 90 papers in his field of research.

Wynblatt holds a BA in metallurgy from the University of Manchester. He earned his MS in metallurgy from the Technion-Israel Institute of Technology, and his PhD in engineering from the University of California at Berkeley. He is a member of the American Society for Metals, American Vacuum Society, Materials Research Society, and The Minerals, Metals, and Materials Society.

Chemometrics Adapted to Multivariate Spectral Measurements

Scientists at Sandia National Laboratories are exploring and developing "chemometrics," a new branch of analytical chemistry, using techniques related to the pattern recognition techniques of artificial intelligence.

Chemometrics allows researchers to systematically sift through vast quantities of data to extract useful quantitative information, based on the spectral characteristics of samples of known composition that the computer has been "trained" to recognize. While it can be applied to a wide range of chemical data, the researchers chose to analyze information acquired through spectral measurements since such measurements are rapid, nondestructive, easily automated, and don't require chemical separations.

The new analytical technique consists of developing, improving, and applying "multivariate" calibration and prediction methods—that is, using spectral data acquired at all wavelengths of interest. Multivariate methods offer analysts several advantages over previous techniques. These include greater precision, higher accuracy, increased reliability, improved identification of suspicious data, the ability to address a new range of problems, and the capability to relate spectra empirically to the chemical and physical properties of the sample.

"The predictive techniques employed in chemometrics greatly reduce the ever-present concern among experimental scientists about data validity," one researcher said. "The methodology allows analysts to detect and reject 'outliers,' samples whose spectra lie outside the data range of the calibrated samples."

Multivariate analysis allows researchers to investigate problems beyond the range of traditional methods. For example, univariate spectrometric methods fail to produce credible, quantitative results if a sample has interfering spectra, contains interacting molecules, or if the spectrometer is nonlinear; multivariate methods overcome these limitations, allowing analysts to construct empirical models to predict an unknown sample's chemical and physical properties.

Software associated with the chemometric technique can be used in process monitoring for the manufacture of integrated circuits and possibly for use in monitoring plasmas during plasma etching.

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DOE, National Center for Manufacturing Sciences Sign Tech Transfer Agreement

The U.S. Department of Energy (DOE) signed an agreement with the National Center for Manufacturing Sciences (NCMS) that will encourage the transfer of unclassified technology from the DOE's defense laboratories into the hands of U.S. businesses. Cooperation may take the form of information exchange, cooperative research, technical workshops, cooperative educational programs, and other agreed-upon activities.

Cooperative work will emphasize advanced manufacturing sciences, including energy efficient and environmentally conscious processes, tools, materials, and techniques that improve manufacturing.

"This historic agreement is a reflection of the new mission of DOE in technology transfer and opening up, to a greater degree than ever before, the Department's three defense national laboratories—Los Alamos, Lawrence Livermore, and Sandia National Labs—to this mission," said Deputy Energy Secretary W. Henson Moore. "This is a drastic change from the years of secretive work done at the labs where business people were virtually excluded."

NCMS is a consortium of more than 125 small, medium, and large manufacturers committed to making U.S. manufacturing globally competitive through development and implementation of next-generation manufacturing technologies. NCMS was incorporated in 1986 under the National Cooperative Research Act of 1984, which enables firms to engage in joint precompetitive research.

Gschneidner Receives Spedding Award

Karl A. Gschneidner Jr., a senior metallurgist at the Ames Laboratory, director of the Laboratory's Rare-Earth Information Center, and a distinguished professor of materials science and engineering at Iowa State University, received the Frank H. Spedding Award this summer at the 19th Rare-Earth Research Conference in Lexington, Kentucky. The award honors Gschneidner for his leadership and distinguished contributions to the field of rare-earth science, especially to the physical metallurgy and solid state physics of rare-earth materials. It is particularly meaningful to Gschneidner, who studied under Spedding at ISU in the mid-1950s. Gschneidner is senior editor of the 14-volume *Handbook on the Physics and Chemistry of Rare Earths.*

"Single-Atom Switch" Demonstrated

IBM scientists have reported the operation of an electrical switch that works by reversibly moving a single atom. Donald M. Eigler, Christopher P. Lutz, and William E. Rudge of IBM's Almaden Research Center reported in the August 15 issue of *Nature* that they had repeatedly moved a single xenon atom back and forth across the gap between two electrodes spaced several atomic diameters apart. They found that the electrical "tunneling" current that flowed between the electrodes changed according to the position of the xenon atom.

The demonstration required a special low-temperature scanning tunneling microscope (STM) to build and operate the "atom switch." One electrode was the STM's tungsten tip and the other a single crystal of nickel, both held stationary about 5 Å apart. First, the STM was used to slide a xenon atom to a kink site on a surface step believed to encourage the xenon atom to bind reproducibly in the same spot.

To operate the atom switch, the researchers applied a short voltage pulse to one of the electrodes. The resulting electrical current caused the xenon atom to jump the gap between the electrodes and attach itself to the surface of the opposing electrode. By reversing the polarity of the voltage pulse, the scientists can return the xenon atom to its original position. The device is in a low-conductance state when the xenon atom is on the substrate, and switches to a high-conductance state when the atom is on the tip.

The researchers attribute the effect to heating-assisted electromigration, the only mechanism they found consistent with their findings.

Mitigating considerations concerning the atom switch include the necessity for operation in a vacuum and at an extremely low temperature, and with an STM, an expensive, bulky device. An additional problem is the switch's speed, which is presently much too slow for practical use. This problem may be circumvented by moving toward massively parallel reading and writing.

"It's not yet clear if one could ever build commercially practical atom switches or devices that use them," Eigler said. "But my hope is that our fundamental research will lay the scientific foundation for future generations of very small electronic devices, including those that may someday be mass-produced on an atomic scale."

More Ductile Family of High T_c Superconductors Discovered

A more ductile family of high-temperature superconducting materials that conducts electricity only along the planes formed by copper and oxygen atoms when they are separated by nonconducting chains has been announced by researchers at Argonne National Laboratory and Northwestern University. In most conventional high-temperature superconductors, the copper and oxygen planes have been separated by conducting chains or planes, and researchers had focused on the relationship between the planes and the chains to study the nature of high-temperature superconductivity.

Tests show that the new compound, a mixture of oxygen, copper, gallium, strontium, and yttrium becomes superconducting at 73 K. The use of the metals gallium and copper forms a novel spacing structure between the copper-oxygen planes of the compound, which apparently results in better thermal and mechanical stability.

During processing, the material is doped by replacing 30% of the yttrium with calcium. The compound is then subjected to high oxygen pressures to become superconducting.

Northwestern and Argonne are partners in the National Science Foundation's Science and Technology Center for Superconductivity, which funded the research. Other partners in the center are the University of Chicago and the University of Illinois.

NSF Funds Materials Chemistry Curriculum Project

The National Science Foundation is funding a curriculum development project to incorporate more solid-state and materials chemistry into the freshman chemistry curriculum. This is a response to the evolving needs of the students required to take chemistry in fields ranging from engineering to premedical studies.

The project, a multi-university effort centered at the University of Wisconsin in Madison, aims to develop new lecture/lab demonstrations, laboratory experiments, software, and text materials to explain the main principles of chemistry and to supplement presently available material predominantly based on small-molecule chemistry (primarily gases and solutions).

Rather than recreate information already present in the materials science community, the curriculum developers ask that anyone with related existing curriculum

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material contact one of the area coordinators: Prof. Arthur B. Ellis, Materials Science Program and Chemistry Dept., University of Wisconsin, Madison, WI 53706; Prof. M. Stanley Whittingham, Materials Research Center and Chemistry Dept., SUNY, Binghamton, NY 13902-6000; or Prof. George Lisensky, Chemistry Dept., Beloit College, Beloit, WI 53511.

The project also needs departments willing to act as test sites for the material developed. Tests should begin in the fall of 1992, with tested material being generally available for fall 1993.

Nerve Cell Joined to Silicon

Researchers in the University of Ulm's Biophysics Department have achieved a tight electric junction between a single neuron removed from a leech and silicon, as reported in the May 31 issue of *Science*. The junction behaved like a field-effect transistor, potentially providing a better understanding of complex neural systems if single-neuron technology works for networks.

This initial advance toward multiple recording in neurons and neural nets could lead to the development of neural biosensors and neuroelectronic circuits, the researchers say.

The neuron, a Retzius cell, was mounted on a thin insulating layer of a gate oxide on Si, with the arrangement surrounded by an electrolyte. The neuron acted as a current modulator between the Si source and drain. Interaction proceeded from the direct coupling of cell membrane and gate oxide without metallic intervention.

NSF Seeks Nominations for 17th Alan T. Waterman Award

Nominations of candidates for the 17th annual Alan T. Waterman Award are being accepted by the National Science Foundation. Intended to encourage high-quality research, the award recognizes an outstanding young researcher in any field of science, mathematics, or engineering, and consists of a medal and up to $500,000 for up to three years of research or advanced study at the institution of the recipient's choice. Candidates should exhibit quality, innovation, and potential for discovery in their research.

Nominations may be submitted by individuals, professional societies, industrial companies, and by other appropriate organizations within the scientific, engineering, and educational communities. Nominations for the 1992 award must be received by the award committee at the National Science Foundation by **December 31, 1991**.

For additional information or a copy of the nomination form, contact: Susan E. Fannoney, Executive Secretary, Alan T. Waterman Award Committee, National Science Foundation, 1800 G Street NW, Room 545, Washington, DC 20550; phone (202) 357-7512.

Brite/Euram "Information Days" to Be Held in Europe

The European Commission is organizing a series of "Information Days" throughout Europe to promote participation in the new program, Industrial and Materials Technologies (Brite/Euram II), this fall, with the aim of rejuvenating European manufacturing by strengthening the scientific industrial base through research and technological development work, and encouraging the integration of new technologies.

The Brite program was begun in 1985 and funded 215 projects, while the separate Euram program started in 1986, supporting 91 projects. The programs merged in 1989, and with a budget of 500M ECU (1 ECU = $1 US) funded some 380 collaborations. Another merger followed with the Raw Materials and Recycling initiative, which since 1990 had supported 69 projects at 23M ECU.

The current organization will run until 1994 with a budget of 670M ECU. Its major areas of interest are materials and raw materials, design and manufacturing, and specific activities relating to aeronautics. Industries, universities, and research institutions in small collaborative international groups may apply for project funding in these areas.

Information Days will be held in Milan, Italy, October 24-25 and in Madrid, Spain, November 21-22. A final proposers' forum will be conducted in Brussels, Belgium, December 10-11. The Swedish government, in collaboration with the Commission, is also organizing Information Days for December 2-3.

The European Commission will also hold the fourth Brite/Euram Conference and Exhibition during the 1992 Sevilla Universal Exposition (EXPO 92) May 25-27, 1992.

For more information, write to: 200, rue de la Loi, B-1049 Brussels, Belgium.

MRS