Microlithography Demonstrated Using Neutral Atoms Instead of Light

A form of microlithography that uses neutral atoms instead of light to write patterns on silicon has been demonstrated by scientists from Harvard University and the National Institute of Standards and Technology. The scientists' results are reported in the September 1 issue of *Science.*

"Our technique," said Andreas Bard, a guest researcher at NIST, "uses metastable, noble gas atoms to pattern a very high resolution lithography resist made with a single layer of molecules." Noble gases in their ground state are inert and do not interact with other elements, but when the atoms are excited to a metastable state, their electrons carry stored energy. Upon impact with a surface, the atoms release their stored energy to break chemical bonds. The wavelength of individual metastable atoms is less than 0.01 nm, which makes the stream of atoms a much sharper "writing tip" than light, which has wavelengths that are more than a 1,000 times bigger.

The resist used in the Harvard/NIST method is a self-assembled monolayer of organic molecules called alkanethiolates which is adsorbed on the surface of the gold. The thiol ball of the molecule bonds strongly to the gold, while the hydrocarbon chain floats away from the surface. On gold and a number of other metallic and oxide surfaces, these and other appropriate compounds will self-assemble into a single layer of tightly packed molecules a few nanometers thick, much thinner than a typical photoresist.

The research group's experiments involved directing a beam of metastable argon atoms through a copper grid or screen with holes about 10 micrometers across. Wherever the metastable atoms hit the self-assembled monolayer resist, they released their energy and broke hydrocarbon bonds. Areas of gold underneath the weakened and damaged bonds were then washed away with a chemical bath. The result is a grid of gold lines a few micrometers wide with extremely sharp edges (less than 100 nm roughness). The gold features can then be chemically transferred into the silicon base, leaving a pattern in the silicon.

In the current experiments, the group used laser light to selectively quench or turn off metastable atoms. The laser light releases a metastable atom's stored energy before it reaches the resist surface. A beam of laser light intersecting the metastable atoms' path was used to protect certain areas of a resist, while exposing others. According to Karl Berggren of Harvard, the combination of laser patterning with a metastable atom/self-assembled monolayer resist system may produce circuit features only 10s of nanometers wide.

NIST Announces 44 ATP Awards

In September, the Advanced Technology Program under the National Institute of Standards and Technology announced 44 industry-sponsored projects in five key technology areas that will receive cost-shared funding for research and development involving approximately $192 million in cost sharing by private industry and approximately $188 million in ATP funding.

Fifteen awards are for projects in motor vehicle manufacturing technology, six awards for projects supporting digital video in information networks, nine awards for projects in catalysis and biocatalysis technologies, seven awards for projects in component-based software, and seven awards for projects in manufacturing composite structures.

For more information about each project, contact Advanced Technology Program, National Institute of Standards and Technology, Administration Bldg.

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101, Rm. A430, Quince Orchard & Clopper Roads, Gaithersburg, MD 20899-0001; or search for ATP news releases on the World Wide Web: http://www.nist.gov/.

Photorefractive Polymer Performs in Dynamic Holographic Interferometry and Optical Correlation Devices

In September, N. Peyghambarian and his research team at the Optical Sciences Center of the University of Arizona built and demonstrated an optical correlator that uses low power semiconductor laser diodes and their high efficiency photorefractive polymer as active material to perform in real time the optical correlation of two randomly generated 64×64 binary phase holograms (see figure below). This technology, based on all-optical correlation in a low-cost photorefractive polymer, is currently being developed by Peyghambarian's team in collaboration with B. Javidi's group from the University of Connecticut to provide an inexpensive verification product that can be used to verify the authenticity of optically encrypted objects such as credit cards, passports, consumer goods, or money.

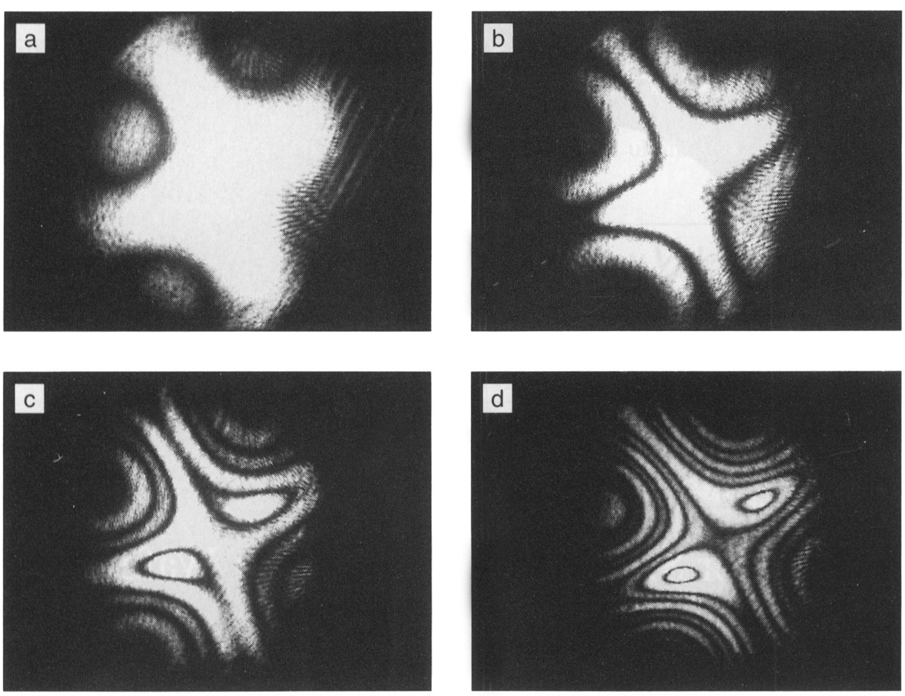
Peyghambarian's report of close to 100% diffraction efficiency and net two-beam coupling gain coefficients in excess of 200 cm^{-1} in a photorefractive polymer, published in *Nature* **371** (1994), drew considerable attention on the potential of optically active polymers for photonic applications. Due to the flexibility of organics, the efficiency of these materials could be improved by four orders of magnitude during a nearly four-year research effort which started with the demonstration of principle of photorefractivity in a polymer by a team at IBM Almaden in 1991. During this short time, these polymers have reached performance levels that are comparable or even superior in some respect, to the best inorganic photorefractive crystals studied during the last 30 years.

Recently, the team at Arizona, including assistant research professor B. Kippelen and two graduate students, strengthened the high expectation for these materials, by demonstrating a variety of applications including holographic storage, published in the January 1995 issue of *Physics Today*, and dynamic holographic interferometry, published in *Optical Processing & Computing* **6** (1995).

Tooth Remineralization Method Licensed to International Health Care Manufacturer

A remineralization method, invented by Ming S. Tung, an American Dental Association Health Foundation research associate in the Paffenbarger Research Center at the National Institute of Standards and Technology, involves the use of amorphous calcium phosphate compounds in a carbonate solution that crystallizes to form hydroxyapatite, the primary mineral in teeth and bone. The process disperses hydroxyapatite into the tooth structure to "fill" the microscopic holes and repair early cavities, making teeth stronger.

In the past, commercialization of a solution for remineralization has been prevented by problems such as instability, slow diffusion and reaction time, and surface precipitation. Tung's calcium phosphate process overcomes these problems and remineralizes teeth rapidly.



Mode patterns of a vibrating membrane for different amplitudes of excitation: (a) 30, (b) 60, (c) 120, and (d) 240 mV. These modes were obtained via dynamic holographic interferometry performed in a DMNPAA:PVK:ECZ:TNF photorefractive polymer developed at the University of Arizona.

Flat-Panel Video Screen Uses Laser Light Source

Brookhaven engineer James Veligdan invented a flat-panel video screen that uses lasers as a light source. The display screen prototype is nine inches wide by five inches high and approximately one inch thick.

Veligdan's technology works by directing light from a miniature laser to a scanner, which guides the light beam into the proper sector of laminated wave guides. Composed of multiple sheets of laminated glass or plastic, the wave guides direct the light to the screen to display the video image.

The system is eye-safe and high-contrast, and it offers wide viewing angles, according to Veligdan. He said the screen can be used in cold weather, whereas liquid crystals thicken and freeze.

Potential uses of the patented device include video advertising displays, television, computers, automotive dashboard, and aircraft cockpit displays, as well as portable military maps and wall-sized displays for home entertainment.

Fluid Convection Through Porous Materials Differs From Theory

By using magnetic resonance imaging (MRI), Duke University researchers have found in laboratory experiments that porous materials such as sand or dirt may steer fluids passing through them into flow patterns substantially different from what theories predict. The results of their research was published in the September 4 issue of *Physical Review Letters*.

Their discovery could complicate the tasks of geologists seeking to predict underground migrations of fluids ranging from polluted water to spilled petroleum, said Duke physics professor Robert Behringer.

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"One of the basic problems in predicting groundwater flow or in undertaking oil recovery is that you have almost no knowledge of the shape of the pores inside of the materials," he said. "I think these experiments show that knowledge is crucial for predicting the flow."

Postdoctoral researcher Mark Shattuck set up an MRI experiment designed to mimic the "convective" flow of water through a porous substance. Fluids are said to convect when heat causes them to flow from a warmer to a cooler region. Convective flows of this kind occur frequently underground, Behringer said.

Convection in porous substances had been studied for a half century, Behringer said. But physicists had been unable to observe how most porous materials interact with convecting fluids, even when the materials are composed of beads of transparent glass. Such beads' curving surfaces refract light, which spoils the transparency. "It's a little bit like looking through a pebbled glass shower door," he said.

In their experiment, the researchers filled a container with plastic spheres and water and placed it inside an MRI magnet. Separate water lines heated one side of the container and cooled the other side to cause a convective flow through the vessel.

The MRI device's computer then revealed, in color-coded patterns, how warmer and cooler convection currents moved through the beads.

Scientists believed that porous materials would form random arrangements when made to fill a container. As a result, fluids were thought to convect through randomly located gaps between grains.

But the researchers found that the plastic spheres instead packed themselves together in a more organized way that resembled the packing of atoms in a crystal. Open spaces formed at boundaries between the crystal-like arrangements of spheres.

As convective flows began, water passed through those grain-boundarylike spaces first. As the flows became stronger, water then tended to find its way through more-restrictive openings as well, Behringer said.

Complex flow patterns developed that did not conform to theory. Instead of the expected regular arrangements of parallel ropelike flow lines, fingers of warmer water initially assumed irregular isthmuslike shapes as they flowed through cooler water. As the speed of warm water increased, the isthmuses then broke up into geometrically-arranged pieces.

However, the physicists found that the ropelike patterns that theory predicted could emerge where the water passed through spheres packed like a defect-free perfect crystal.

Arrangements of porous materials in nature, however, are far less regular than they were in the experiments. "It means that, given these very complicated underground porous structures, you may have a very limited ability to predict what is going on underground," Behringer said.

Still, Behringer thinks the experiments could provide insights that could ultimately lead to more realistic predictions. He suggested developing a kind of "wave theory" for convection analogous to the ones used to predict the movements of electron waves in computer chips.

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Grinding Formula Predicts Surface Finish of Glass

University of Rochester engineers have solved a long-standing problem for the optics industry by developing a formula to predict how well different glasses stand up to the grinding process, a key step in making high-quality optical components unblemished by cracks, waves, and other defects. Engineers working with the University's Center for Optics Manufacturing (COM) presented the results at a meeting of the Optical Society of America in Portland, Oregon in September.

Mechanical engineer John Lambropoulos and graduate students Tong Fang and Su Xu analyzed experimental data collected by engineers in COM's Manufacturing Sciences Group who subjected three dozen types of glass to precise grinding tests and then modeled the tests on a computer. They found that hardness and fracture toughness together account for variations in the grinding process. A glass's hardness is routinely provided by glass manufacturers, while its fracture toughness can be measured using very inexpensive equipment, said Lambropoulos.

"This explains why some glasses become very smooth with very little damage, while some become rough and damaged, even though you're using the same machine, the same operator, and the same settings," said Lambropoulos.

Chaudhari, Cuomo, and Gambino Honored With National Medal of Technology

Praveen Chaudhari, Jerome J. Cuomo, and Richard J. Gambino, who worked together at IBM's Thomas J. Watson Research Center in the 1970s, discovered a combination of elements that possessed unusual magnetic and optical properties that made them suitable media for optical data storage. On September 27, U.S. Secretary of Commerce Ron Brown announced that they would receive the National Medal of Technology, established by Congress, for their discovery.

The materials discovered by Chaudhari, Cuomo and Gambino consist of combinations of rare-earth and transition-metal elements that form amorphous alloys. Their amorphous structure enables the formation of very small and well-defined domains within the material that can still yield strong and low-noise magneto-optic signals.

Chaudhari has received numerous awards and has served on national and presidential advisory councils. He is a member of the National Academy of Engineering, a fellow of the American Physical Society, and vice president of the Council of the International Union of Pure and Applied Physics. Chaudhari holds a PhD degree from the Massachusetts Institute of Technology.

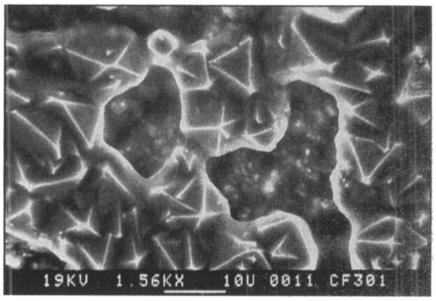
Cuomo, also a recipient of many awards, was elected to the National Academy of Engineering in 1993 and has served on the National Research Council Committee. He is now a Chaired Professor in the Materials Science and Engineering Department at North Carolina State University. Cuomo received a PhD degree from Odense University in Denmark.

Gambino is a professor in the Materials Science and Engineering Department at the State University of New York at Stony Brook. He received his MS degree from the Polytechnic Institute of New York. Gambino has received numerous awards for his research and has also been recognized by engineering and research societies.

Diamonds Grown from Au- and Ag-Containing Liquids at 1 Atm

Researchers at Penn State's Material Research Laboratory have shown how diamonds can be precipitated out of liquid metallic alloys rich in carbon and also containing atomic hydrogen. A wide range of metals have been utilized, including iron, nickel, manganese, silver, gold, and tin: Alloys extraordinarily rich in carbon—up to 70%—can be synthesized at temperatures from 700–1000°C, and the diamond progressively precipitated out. Growth on single crystal diamonds from the metallic alloys has also been achieved.

Rustum Roy and his colleagues who, in 1993, described the low pressure solid state source (LPSSS) process for synthesis of diamond at 1 atm, surveyed metals to determine why some work in the LPSSS process. They first examined metals commonly used in the high pressure, high temperature (HPHT) process. Since Cu does not work in HPHT but is effective in LPSSS, the researchers studied Au and Ag, expecting that they would not work. They mixed five to 10% of Ag or Au with graphite in a 2.45 GHz microwave reactor in the presence of only H at 100 Torr at sample temperatures varying from 750–1000°C. They examined all samples by SEM, XRD, and TEM. A liquid droplet formed, consisting of the metal with carbon and possibly hydrogen, in nearly all LPSSS-metal runs at temperatures hundreds of degrees below the metal-carbon eutectics. They found in a later stage the development within a cavity within such liquid particles of the first euhedral diamond crystals. In their examination, the researchers identified diamond by its Raman spectrum, powder XRD, single crystal electron diffraction, and characteristic morphology.



Diamond crystals forming in an iron-carbon-hydrogen liquid in a microwave plasma below atmospheric pressure.

Silicon Microengine Turns Gears, Operates Shutter

Researchers at Sandia National Laboratories designed and have built a micromotor that drives external gearing. It was built by microelectronic fabrication techniques.

Jeff Sniegowski, who led the effort to build the millimeter-square engine and its gearing, said that the silicon micromotor can be connected to a variety of devices. He said their goal was to develop a generic micromotor that has a gear output, so people could see the power source to which they could attach an application.

The device is built with three levels of polycrystalline silicon. The first level contains the engine, the second the gears that the engine drives, and the third the linkages that connect the engine to gears or other linkages, said Ernest Garcia, a primary designer of the electromechanical components.

The researchers built the micromotor with etching processes and silicon materials already in use by the microelectronics industry.

The basic batch process begins on a silicon substrate. Researchers deposit a layer of electrically insulating material and then a film of polycrystalline silicon, patterned to form electrically conducting lead-ins. Atop these is a layer of "sacrificial" silicon dioxide, so-called because it serves as a support layer only as the remainder of the structure is built. When the silicon dioxide is removed by several etching processes, openings through the oxide allow the next applied layer of

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polysilicon to anchor to the insulating layer on the substrate. The process forms vertical axles for gears and elastic supports for the engine. Other depositions and etchings of the oxide free gears and linkages. During these steps, researchers add silicon nitride, which is hard but smooth, and functions as a lubricant to let the gears turn more freely. As a final step, researchers use hydrofluoric acid to remove all the sacrificial supporting layers of silicon dioxide.

The motor consists of two tiny silicon combs with a shuttle placed between them. The edges of the shuttle form combs with teeth that interdigitate with those of the stationary combs. The stationary combs, energized by on-off electric voltages, alternate pulling the shuttle by an electrostatic attraction.

An attached shaft turns a drive gear in a quarter of a circle during the shaft's power stroke. Another comb-drive engine, at right angles to the first, is timed to turn the gear on the second quarter of its rotation. The two drives, alternating their force, turn reciprocating motion into rotary motion to drive the gear completely around.

The motor develops 0.5 microwatts of power delivered through a gear 50 microns in diameter.

Electronic circuits not part of the micromotor chip drive the motor. The researchers are working to place control circuitry next to the microengine, and to develop a single chip with circuits and machines fabricated side by side.

Complex-Shaped Ceramics Formed by Gelcasting

Engineers at Oak Ridge National Laboratory (ORNL) have developed a process called gelcasting to form high-quality, complex-shaped ceramic parts quickly and cost-effectively.

For the gelcasting process, the researchers combined traditional methods of producing ceramics with polymer chemistry to produce a slurry containing ceramic powder, water, and monomers capable of combining with other molecules. The slurry is poured into a mold of the desired shape. A chemical reaction is then initiated to form a polymer-water gel that locks the ceramic particles in place. The part is removed from the mold, dried, then fired to fully develop its strength and other properties.

The advantages of gelcasting include a relatively short molding time, greater precision than other methods, and minimal defects and warpage of components.

Exo-Melt Process Facilitates Nickel Aluminide Formation for Auto, Steel Industries

To the automotive and steel industries, nickel aluminide is an attractive alloy, but its major drawback is it is difficult to produce. Also, vendors feared that too high an aluminum content would lead to aluminum leakage through furnace wall cracks, attacking the heating coils, and possibly causing an explosion. Researchers at Oak Ridge National Laboratory (ORNL) have developed the Exo-Melt process to safely produce nickel aluminide.

The Exo-Melt process takes advantage of the heat generated in the reaction between nickel and aluminum, said Vinod Sikka, one of the developers of the method. "The reaction that produces the nickel aluminide frees a large amount of heat and is, therefore, called an exothermic reaction," he said. This heat increases the efficiency of the process that creates nickel aluminide by dissolving the alloying metals to produce additional nickel aluminide.

The Exo-Melt uses as much as 50 percent less electricity than is required by other alloy-manufacturing processes.

STM, Supercomputer Used to Describe Si(5 5 12) Surface

A team of scientists at the Naval Research Laboratory (NRL) has reported an atom-by-atom description of a recently discovered stable surface of silicon, Si(5 5 12). The team used STM, in combination with supercomputer-based calculations, to arrive at a complete structural model for this complex crystal face. As reported in the September 15 issue of *Science*, Si(5 5 12) joins a select few surfaces of silicon whose structures have been determined.

The research team said silicon surfaces are the most widely studied of all semiconductors. While most electronic devices are fabricated on Si(001), other silicon surfaces are being investigated. According to the research team, "Determination of the complex Si(5 5 12) structure enhances our general understanding of silicon surfaces, and will hopefully improve our choice of substrates for novel electronic devices."

"This face of silicon has one of the largest periodic structures ever observed and is stabilized by a complex rearrangement involving every atom on the surface. Critical in the characterization of surfaces on the atomic scale is the joint efforts of both theorists and experimentalists," said the team.

The characterization of Si(5 5 12) demonstrates how the structure of a very complicated semiconductor surface can be understood in terms of a small number of simple building blocks that reduce the number of dangling bonds, provided that the composite structure has a low net strain energy. "Only by simultaneous consideration of both dangling bonds and surface stress will progress continue to be made in the understanding of very large-scale semiconductor surface reconstructions. As the feature size of silicon-based electronic devices approaches the nanometer scale, such progress will become increasingly important," said the research team.

Erdogan Receives Adolph Lomb Medal

Turan Erdogan, University of Rochester, received the 1995 Adolph Lomb Medal from the Optical Society of American "for application of electron-beam lithography to fabrication of circular diffraction gratings and demonstration of a surface-emitting semiconductor laser based on these gratings."

Erdogan received BS degrees in physics and electrical engineering from the Massachusetts Institute of Technology in 1987, and his PhD degree in optics from The Institute of Optics at the University of Rochester in 1992. He has received various fellowships and is currently assistant professor at The Institute of Optics.

Johnson, Kwok, and Patel Named OSA Fellows

Kristina Johnson of the University of Colorado at Boulder was named a fellow of the Optical Society of America for "contributions in the field of optical computing, especially for achievements related to smart pixel arrays and optical neural networks."

Hoi-Sing Kwok of State University of New York at Buffalo was named fellow for "contributions to the understanding of the pulsed laser deposition process for superconducting and optical thin films."

Jay S. Patel of Bellcore in Red Bank, New Jersey, was named fellow for "contributions to the understanding of liquid crystals and applications of liquid crystals to optoelectronic devices."

Abraham Receives Research Award from The Electrochemical Society

Kuzhikalail M. Abraham of EIC Laboratories is the recipient of the Research Award of the Battery Division of The Electrochemical Society, Inc. Abraham's battery research has centered on four principal areas: studies of the chemical and electrochemical processes in the Li primary battery systems; novel rechargeable Na batteries operating in the moderate temperature range of 100–200°C; fundamental studies of Li electrode rechargeability in organic electrolytes and the development of ambient temperature rechargeable Li batteries; and polymer electrolytes with high ambient temperature conductivity and solid-state Li batteries containing them. This research has resulted in 100 technical papers published, 12 U.S. patents, and numerous meeting presentations.

Abraham received his BS and MS degrees in chemistry from Kerala University in India in 1965 and 1967, respectively, and his PhD degree in inorganic chemistry from Tufts University in 1973.

Pantelides Named Distinguished Scientist at ORNL

Sokrates T. Pantelides has been named a Distinguished Visiting Scientist at Oak Ridge National Laboratory (ORNL) through its Distinguished Visiting Scientist and Engineers Program. Pantelides is the William A. and Nancy F. McMinn Professor of Physics and chair of the Department of Physics and Astronomy at Vanderbilt University.

"I welcome the invitation from colleagues at Oak Ridge and view this appointment as a way to broaden our research programs and to expand mutually valuable connections between Vanderbilt and the Oak Ridge National Laboratory," said Pantelides.

Pantelides is a world-renowned theoretical physicist with a long and eminent career in research and research management at the IBM Thomas J. Watson Center in Yorktown Heights, New York. He spent a sabbatical as professor of theoretical physics at the University of Lund in Sweden before joining the Vanderbilt faculty in 1994.

His research involves pioneering theoretical research bridging the gap between atomic-scale structure and the physical properties of real materials. His research forms the basis for a broad range of collaborations in such areas as condensed matter theory, ion implantation, interface science, and high-resolution x-ray research.

He received his doctorate in physics in 1973 from the University of Illinois and held a postdoctoral fellowship at Stanford University. Pantelides has published more than 150 scientific papers, edited or co-edited six books, serves on editorial boards of several journals and for five years was a contributing columnist for *The Scientist*. □