Scientists Produce MEMs Nanoguitar

A "nanoguitar" 10-μm long and carved out of crystalline silicon is one of several structures that have been made at Cornell University to demonstrate technology that could have a variety of uses in fiber optics, displays, sensors, and electronics. Researchers made these devices at the Cornell Nanofabrication Facility, bringing microelectromechanical devices (MEMS) to the nanosized scale. The guitar has six strings, each string about 50 nm wide. If plucked—by an atomic force microscope, for example—the strings would resonate, but at inaudible frequencies.

The key to the technology is electron-beam (E-beam) lithography. E-beam lithography is a technique for creating extremely fine patterns required by the modern electronics industry for integrated circuits. Derived from the early scanning-electron microscopes, the technique consists of scanning a beam of electrons across a surface covered with a thin film, called a resist. The electrons produce a chemical change in this resist, which allows the surface to be patterned.

Most microelectromechanical devices are made by photolithography and chemical etching and have minimum feature sizes of slightly less than 1 μm. To build devices with dimensions of nanometers rather than micrometers requires a new fabrication approach.

Using high-voltage electron beam lithography, Harold G. Craighead, professor of applied and engineering physics, and doctoral student, Dustin W. Carr sculpted their structures out of single crystal silicon on oxide substrates. A resist is used to pattern the top silicon layer. The oxide that is underneath this layer can be selectively removed using a wet chemical etch, resulting in free-standing structures in silicon crystal.

"The nanomechanical devices will also allow further exploration into important physical questions regarding motion and mechanical energy dissipation," the researchers wrote in their report presented at the 41st Electron, Ion, and Photon Beam Technology and Nanofabrication Conference in Dana Point, California in May.

An efficient and relatively non-invasive method of measuring the small motion of the mechanical structures is performed by using the interference of laser light beams. The researchers have made a Fabry-Perot interferometer using this technology. These interferometers use parallel mirrors, one of which moves relative to the other. The motion is detected by variations in the reflected light. The devices currently under study in Craighead's laboratories are moved by electrical forces. These electrically driven devices can be used to modulate the intensity of the reflected light. "This could be of interest for light displays," said Craighead. "You could have arrays of these things because they're so small, with each one independently driveable. We have tremendous flexibility in what we can build."

In the near term, such nanostructures also can be used to modulate lasers for fiber optic communications. The researchers already have demonstrated the ability to make large amplitude modulation of light signals at high speeds. "We can make reflected light pulses at a rate of 12 million per second," Craighead said. Such a rate is faster than the bit rate of most ethernet connections.

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The structures also are extremely sensitive to very small forces. "We make these structures move and measure the motion by placing single electrons on the surface of the devices," Carr said.

Craighead said, "I know we can go smaller than this. The question is how small we can go and still have dependable and measurable mechanical properties."

Solar Cell Production Time Cut in Half, Process Maintains Efficiency

Researchers have successfully cut in half the time it takes to make a silicon solar cell without diminishing its performance, an achievement that should reduce the cost of solar energy. Using rapid thermal processing (RTP), researchers at the Georgia Institute of Technology have produced a solar cell with the same efficiency rating of 18% as one made by conventional furnace processing. The researchers created the cells in 8.5 hours, compared with the 17 hours needed for a furnace-processed cell.

In a separate process, researchers also integrated RTP with screen-printing, an alternative method for applying the cell's metal contacts, which cut the processing time to 1.5 hours.

A paper presented by Ajeet Rohatgi, a professor in Georgia Tech's School of Electrical & Computer Engineering, at the 14th European Photovoltaic Solar Energy Conference and Exhibition in Spain in July describes three steps of the rapid thermal process: a three-minute rapid thermal diffusion that simultaneously forms the front and back of a silicon solar cell; a five-minute rapid thermal oxidation (RTO) for the front emitter surface; and the application of metal contacts by evaporations and photolithography.

In current industrial production, front and back diffusions are done separately. Each step takes one to three hours, and the cells must be cleaned between each procedure. The solar cell then goes back into a high-temperature furnace for the process of passivation in which an oxide is grown on the front surface of the cell. Although passivation improves performance, many manufacturers delete it to save money and increase output.

Rohatgi's research team's RTO process offers a time-saving way to include this step. Forming the metal contacts by evaporations and photolithography accounts for over 80% of the RTP process. Although these procedures give good resolution and conductivity, Rohatgi said commercial manufacturers often use screen printing—an alternative method for adding the metal contacts to a solar cell—instead. Screen printing is quicker but produces less efficient cells.

The researchers successfully integrated screen printing with RTP in 1996 and have since raised cell efficiency from 14.7% to 16.3%. They expect to increase it to 18%, which is the same level already reached for cells produced by RTP and photolithography—with further modifications. These include adding rapid thermal oxidation, a screen-printed aluminum back surface field (to prevent the loss of light-generated carriers to recombination on the back), and surface texturing (to reduce the amount of light reflected off the front surface and trap more light into the cell).

"Today, industrial cells made with crystalline silicon are in the range of 11 to 15%," Rohatgi said. "If we succeed in what we're doing, we will end up making

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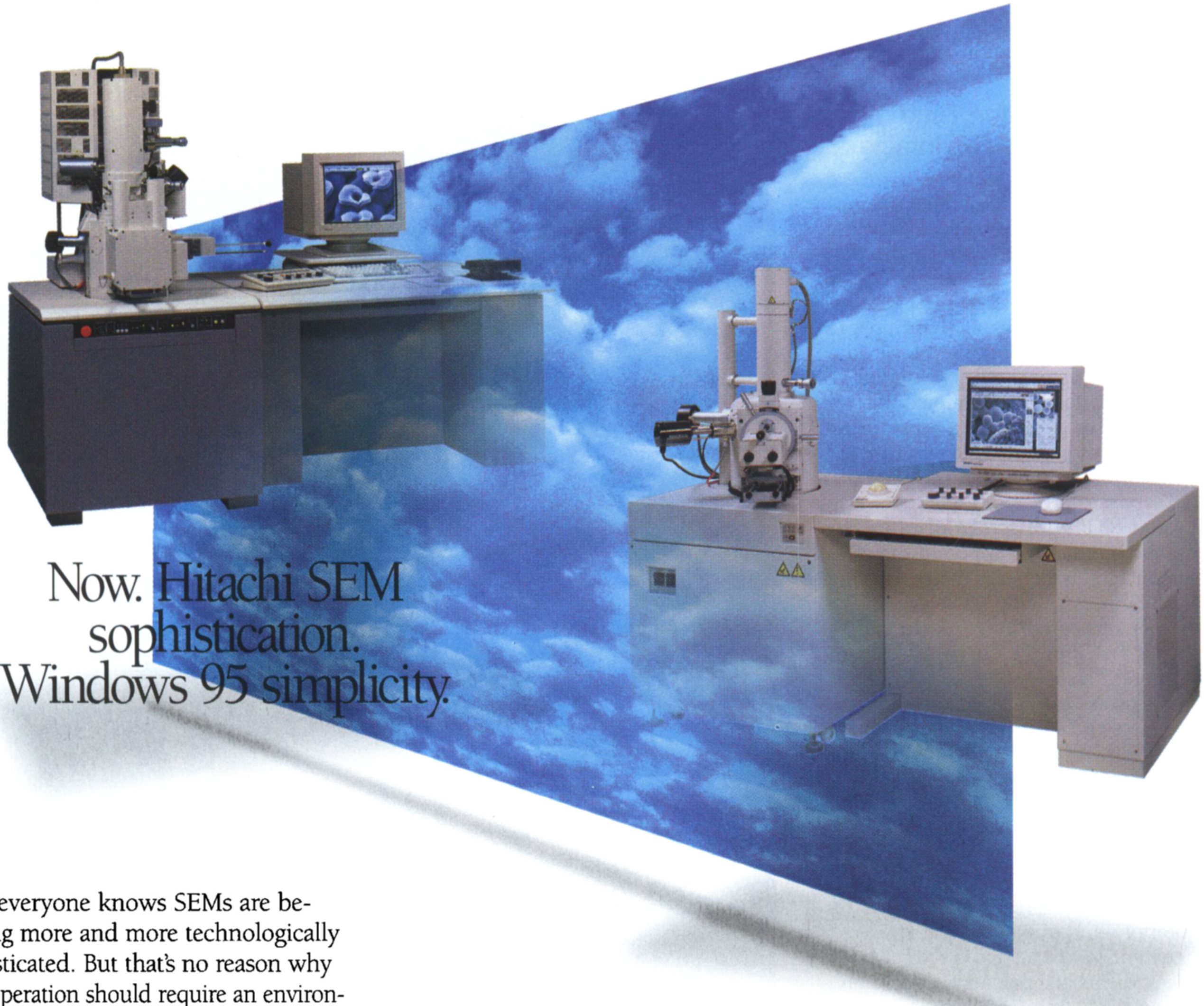

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cells that are close to 18%, in less than one-half to one-third of the time."

For the paper presented in Barcelona, researchers also used modeling and analysis to show how these same modifications could improve cells produced by RTP and photolithography. In late June, they produced a solar cell with 19% efficiency, which is the highest rating achieved with a low-cost, rapid (nonfurnace) process.

Biomolecules Patterned on Gold Glass and Silicon Using Microfluidic Networks

Using microfluidic networks to pattern biomolecules with high resolution on a variety of substrates—including gold, glass, and polystyrene—scientists at IBM's Zurich Research Laboratory in Switzerland have demonstrated the ability to conserve the natural state of a protein while requiring only microscopic quantities of their solution. The method has application to the integration of molecules directly with silicon chips, important to the development of biological sensors needed for efficient medical diagnostics. Existing biological sensors typically use areas at least several millimeters in dimension, consuming large amounts of material in their preparation while allowing only one type of biological molecule to be present and thus only one type of test. "We use microfluidic networks to guide tiny quantities of proteins across a surface with great accuracy and precision," said Emmanuel Delamarche of the IBM team. "Special rubber stamps, inspired by developments in microscopic molding of polymers at Harvard University in the group of Professor Whitesides, form the reusable networks of microchannels directly pressed onto a substrate. The topology of the networks is defined by conventional lithography in silicon, and the networks result by duplication of this topology in the polymer rubber stamp. Active proteins can thus be guided and fixed in place on the substrate in a predetermined pattern that follows the twists and turns of the microchannels."

Each channel of the microfluidic network is independent of the others so that many different proteins can be attached to distinct regions on the surface simultaneously. Biochemist André Bernard, coauthor of the report published in the May 2 issue of *Science*, said that other, more traditional forms of patterning materials, like those used to make computer chips, are often poorly suited to patterning functioning biological proteins. "Irreversible damage to these molecules occurs under the harsh conditions typical of semiconductor processing. Microfluidic networks, in contrast, allow the proteins to remain in an environment similar to normal cells, minimizing their disruption and preserving their function."

In their experiments, the researchers were able to fix antibodies to specific regions of the surface of a silicon wafer using a microfluidic network. After the network was removed, by peeling it off the silicon wafer like a moderately tacky tape, the silicon wafer was placed in a solution with a complex mixture of other proteins. Wherever a protein in solution recognized its partner on the surface a fluorescent light could be easily seen with an optical microscope. This type of observation could also be carried out with photographic film or charge coupled devices like those found in video cameras—light signaling the presence of a given protein. The analysis is similar to more conventional methods already used in hospitals and research laboratories to characterize many types of diseases, although the approach of the IBM scientists allows the detection to occur in an area many times smaller.

Microlithography Yields Polymers That Emit Patterns of Light

Researchers have created a light-emitting diode (LED) made of polymers that can be treated with chemical techniques to emit distinct patterns of light. To make the LED, researchers at the University of Rochester and Hewlett Packard's (HP) Solid State Technology Laboratory used on polymers the same microlithographic technique used to emblazon silicon circuitry.

Guillermo Bazan, an associate professor of chemistry at the university, graduate student Michelle Renak, and HP researcher Daniel Roitman made the patterned LED by implanting a poly(paracyclophene) film with the compound triphenylsulfonium trifluoromethanesulfonate, a photoacid generator that produces triflic acid when exposed to light. When the film reacts with the acid, it is converted to poly(p-phenylenevinylene), which has the light-emitting properties characteristic of a LED and is one of the best-conducting plastics known.

Scientists produce patterns of light by placing a "mask"—essentially a cover with a pattern of holes cut into it—over the light-sensitive polymer mix before it is exposed to light. When the light shines through the mask, the triflic acid produced remains localized in the spots that were illuminated, and distinct patterns of light-emitting regions are created. The LED emits individual pinpoints of light only 5 μm in width.

Bazan's research team has worked on a LED that can emit pinpoints of different colors of light. According to Bazan, the microlithographic technique might also be used in the future to make polymer microchips by patterning conducting grids on polymers, much as silicon chips are now made.

Bazan said, "With this work, we've cracked the problem of how to produce patterns of light with a single LED."

Multilabs Fabricated on Single Silicon Chip

Fred Regnier, a professor at Purdue University and co-founder and chief technical officer of PerSeptive Biosystems, has developed miniature laboratories on a single silicon chip, which was presented June 27 at the International Symposium on Column Liquid Chromatography in Birmingham, England. Regnier said, "What makes this device unique from similar devices under development is that we have found a way to create tiny, rectangular 'particles' within the channels. These monolith structures, etched into the column as a single unit, serve the same purpose as the packing materials used in conventional chromatography columns, and they allow the miniature laboratory to perform more complex procedures."

The miniature laboratories can be used

SBIR Update

UTRON, Inc. (Manassas, Virginia) has been awarded a Phase I SBIR contract from the Ballistic Missile Defense Organization to investigate explosive bonding of dissimilar materials without using explosives. Tailored pulsed power generated pressure pulses replace chemical explosives. Phase I work will establish the point design requirements for titanium and molybdenum cladding on aluminum substrates and design a prototype structure to produce bonded samples. UTRON seeks a joint venture partner to assist in prototype development of the technology during the anticipated two-year Phase II R&D follow-up effort, and in the subsequent Phase III commercialization effort. For more information contact F. Douglas Witherspoon, Executive Vice President, UTRON, Inc., 8506 Wellington Road, Suite 200, Manassas, VA 20109-3915; 703-369-5552; fax 703-369-5298; e-mail fdwitherspoon@compuserve.com.

to chemically separate mixtures into pure components. Such separations, called capillary electrochromatography (CEC), frequently are used in clinical analyses of blood and tissue samples, medical research, and drug discovery. In standard chromatography, a solution to be separated is poured through a tube or column packed with various particles that are coated with a chemical compound. The different components of the solution are attracted to the particles with different affinity, and as the mixture flows through the column, it separates into a series of zones, each containing a pure substance.

The miniature laboratories employ the same principle. Channels and microscopic "particles" are created using photolithography and chemical etching, the same technologies that are used to build semiconductors. The laboratory is cut from a single piece of silicon. Liquids are moved on the chip by voltage applied at the ends of the channels.

Despite their diminutive size, the laboratories on a chip can obtain accurate measurements using only a fraction of a drop of liquid.

"Instead of using microliters of liquid, as is normally done, we use picoliters. Using these tiny amounts of sample, measurements can still be made to within a few percent accuracy," Regnier said.

Although the tiny laboratories will be able to perform many of the same functions as standard chromatographs, their miniature stature does limit their capacity, according to Regnier. He said, "Standard chromatographs are sometimes used to purify products, such as human growth hormone. Because of the minute amounts of liquid used in these mini labs, it would not be feasible to use them to purify products. These devices are designed to analyze, and that they can do very well."

Hollow Nanoparticles of WS_2 Show Lubricating Properties

Scientists at the Weizmann Institute of Science have shown that, when compared to solid lubricants 2H-MoS_2 and 2H-WS_2, hollow nanoparticles (HN) of WS_2 have superior properties as a machine lubricant in tests simulating industrial conditions. When compared with the other lubricants, as reported in the June 19 issue of *Nature*, the material reduced friction between moving metal parts to less than half, and also cut wear on parts by up to six times.

Professor Reshef Tenne of the Institute's Materials and Interfaces Department realized that the tungsten disulfide fullerene-like molecule shows properties that make it particularly suitable for use as a lubricant. Its round shape means it does not adhere to other substances, and it is larger than the carbon fullerene, enabling it to maintain a significant distance between two moving metal parts. In addition, it is made up of many layers of balls so that if the top layer wears away, those underneath continue to maintain a lubricating action.

Tenne said, "Existing lubricants contain

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crystallites, which are shaped like flat platelets and have chemically reactive edges. In working conditions, they stick to machinery parts and undergo chemical reactions that lead them to decompose and rub off. In contrast, our molecules are round and inert, so they just roll against each other and against the machinery parts, and don't stick to anything, like Teflon."

According to Tenne, using the material as a lubricant would significantly increase the lifespan and efficiency of machinery from power tools and motor vehicles to airplanes and satellites.

Combination of Two Types of Transistors Results in Reduction of Chip Size and Power Consumption

Researchers at the University of Illinois at Urbana-Champaign have developed a method of combining two types of transistors in high-performance devices with a variety of applications, including wireless products and optical communications. The devices were fabricated on an indium phosphide heterostructure grown by molecular beam epitaxy.

Ilesanmi Adesida, a professor of electrical and computer engineering and a researcher in the university's Microelectronics Laboratory, said, "Compared to circuits employing only conventional depletion-mode technology, circuits that utilize both enhancement-mode and depletion-mode technology enjoy several advantages, including a reduction in both chip size and power consumption. In addition, the integration of both types of transistors allows for single power-supply operation in circuits, which is difficult to achieve with depletion-mode-only technology." According to the researchers, whose findings appear in the June and August issues of *Electronic Device Letters*, these high-performance devices are ideally suited for high-speed digital applications.

Latex Gloves Offer No Protection Against Dimethylmercury

Dartmouth College professor Karen E. Wetterhahn has died of mercury poisoning obtained during her research on heavy metals. As reported in the September 1997 issue of *Scientific American*, while using dimethylmercury as a standard for mercury measurements, Wetterhahn inadvertently spilled a little of the toxic material on her gloves. The dimethylmercury seeped through her gloves and into her skin, causing Wetterhahn to suffer from mercury poisoning. Her colleagues at Dartmouth College have since run an independent study, published as a letter in the May 12 issue of *Chemical and Engineering News*, in which they determined that dimethylmercury permeates disposable gloves in 15 seconds or less.

Single Polymers Vibrate Harmoniously, Unknot Unpredictably

Steven Chu's research team at Stanford University has published two important discoveries regarding polymers. The idea that the motions of a polymer can be described by a set of frequencies corresponding to a fundamental tone and its higher harmonics, similar to the vibrations of a musical string, is commonly known. But most researchers have considered this linear theory to be a rough description of the actual motion. They have held that, in the real world, polymers submerged in a solution and capable of forming knots make polymer behavior complex and less easy to predict.

In an article published in the July 10 issue of *Nature*, Chu, a physicist, said, "We decided to take the analogy to the guitar string very seriously and see how well it held up. It turned out to be much closer than we expected."

To study individual polymer vibrations, Chu's research team started with strands of DNA 20 μm long immersed in water that had been labeled with a fluorescent dye. Next, they attached tiny plastic spheres about one-third of a micron in diameter to each end of the spaghetti-like molecules. Then, using optical tweezers, they gripped the spheres at each end of a DNA strand and pulled them far enough apart to stretch the molecules to about three-quarters of their full length.

While DNA is normally too small to see with an optical microscope, the dyed strands showed up clearly, so the scientists were able to videotape the vibrations. The Brownian motion acted like tiny fingers plucking at the strand. When the researchers analyzed these movements, they found that the movements could be described by the motion of a set of independent harmonic tones to an accuracy of better than 1%. They carried their analysis up to the eighth harmonic.

Pierre-Gilles de Gennes, professor of the Collège de France and recipient of the Nobel Prize for his contributions to polymer science, had developed a scaling theory that describes the dynamics of a polymer without having to linearize the equations that describe its motion. Chu said, "When we started this work, we sided with de Gennes and felt that polymer motion cannot be perfectly linear. But we looked very hard for nonlinearity and found no evidence for it." The researchers are continuing their search for a breakdown of the harmonic model.

Chu's second study, published in the June 27 issue of *Science*, shows that identical polymers in identical conditions act differently, indicating that small random conditions play an unexpectedly important role in the way polymers unravel. In this experiment Chu's research team observed how immersed DNA strands unravel when exposed to microscopic currents which they manufactured by using microfabrication techniques to create flow channels that were 650 μm wide and 220 μm deep. Fluorescently labeled DNA molecules flowed down one channel until they reached the center of the cell where they moved into a cross current. The researchers videotaped the molecules as they reacted to the cross-current by unraveling to a greater or lesser extent. Observation of thousands of individual, but identical, molecules showed the researchers that the elongation process follows a number of different scenarios and the rate at which they unwind depends dramatically on the initial shape of the partially coiled polymers.

Theorists have described the elongation of these molecules according to a mean-field theory that assumes the description of the average behavior is adequate. Since previous polymer experiments probed the behavior of a large collection of molecules, the mean-field theory was developed that fit the experimental data.

The unexpected outcome of Chu's experiment was that apparently identical polymers exhibit what de Gennes has called "molecular individualism." As de Gennes said in a comment on Chu's article in the same issue of Science, "Normally, the average coil shape is enough to describe many features. But not here."

This individualism apparently arises from small random conditions. "We have found that random thermal fluctuations in the initial starting point of the elongation get magnified into dramatic differences in the way each molecule unravels," Chu said.

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