Optical Switch Triggered by Chiral Molecules May be Basis for Rewritable 3-D Storage

A light-activated optical switch under development at the Georgia Institute of Technology could be the basis for a rewritable three-dimensional data storage system. By utilizing a small number of "trigger molecules" to induce a phase transition in liquid crystal materials, the system would write, read, and erase information using different forms of polarized and unpolarized light.

"The idea is that you would write to the liquid crystal with circularly polarized light, read it with linearly polarized light, and erase it with unpolarized light," said Gary B. Schuster, professor of chemistry at Georgia Tech.

Operation of the optical switch is based on "chiral" molecules that Schuster and his co-workers use to trigger changes in the liquid crystal. Chiral molecules exist in right-handed and left-handed forms. Each form is affected differently by circularly polarized light, which also exists in right-handed and left-handed versions.

When right-handed trigger molecules are struck by left-handed light, for example, they may be converted preferentially to left-handed molecules. If the chiral molecules are dissolved in a liquid crystal material, this structural change can be used to prompt a phase transition in the crystal.

The phase transition alters the optical properties of the liquid crystal material, and one way that change can be detected is by passing linearly polarized light through the crystals. Because the linearly polarized light can be at a wavelength that does not affect the chiral trigger molecules, reading the stored information would not alter it.

Multiple phase transition "switches" could therefore be used together to store digital information.

When the information was no longer needed, it would be erased from the liquid crystal by shining unpolarized light through it, reversing the phase changes originally made by the circularly polarized light. Returning the storage material to its original state would make the system rewritable, and of significant potential value as a computer data storage media, for example.

Schuster and graduate student Jennifer Galvin are developing trigger molecules made up of bicyclic ketones substituted with a styrene group. These materials appear to satisfy most criteria needed for a two-dimensional switch and have set a record for the magnitude of their response to circularly polarized light.

To make a three-dimensional system, the liquid crystals and their dissolved trigger molecules would need to be dispersed in a polymeric material. Microdroplets of the liquid crystal, perhaps less than a micron in size, could then be addressed individually or as groups.

Because the system would be optically based, multiple beams of light could be used to simultaneously write information to the data storage media without interference. That optical advantage would permit large amounts of information to be packed into a relatively small space, facilitating the further miniaturization of computer systems.

Though the Georgia Tech system shows promise, Schuster said that much work remains to be done before it could reach practical application.

ZrW_2O_8 Shrinks When Heated Over Wide Temperature Range

Scientists at Brookhaven National Laboratory (BNL) have discovered that a zirconium compound, ZrW_2O_8, shrinks when it is heated. As reported by researchers from Oregon State University and BNL in the April 5 issue of *Science*, the compound zirconium tungstate, made of zirconium, tungsten, and oxygen, instead of expanding when it was heated to temperatures ranging from near absolute zero to 1050 K, underwent negative thermal expansion.

BNL physicist Tom Vogt said, "It is thought that the oxygen atoms within the compound vibrate more strongly at increased temperatures, pulling the zirconium and tungsten atoms together." Each tungsten atom binds to four oxygen atoms while each zirconium atom binds to six oxygens, constraining movement of the tungsten and zirconium atoms when heated. However, when heat is added to the crystal, the oxygen atoms, flanked by the other two elements, vibrate, pulling the tungsten and zirconium atoms closer together. Because the lattice has large voids, the oxygen atoms do not push out neighboring atoms.

At the BNL High Flux Beam Reactor (HFBR), the material was heated to different temperatures and placed in the diffractometer for examination. The resulting images gave exact locations for each zirconium, tungsten, and oxygen atom inside the sample. By analysis of the atoms' location shifts over the entire temperature range, the compound's shrinking properties came to be known.

This behavior, the researchers said, makes the compound useful for the manufacturing of a broad range of products to prevent the warping and cracking that often occur when materials are exposed

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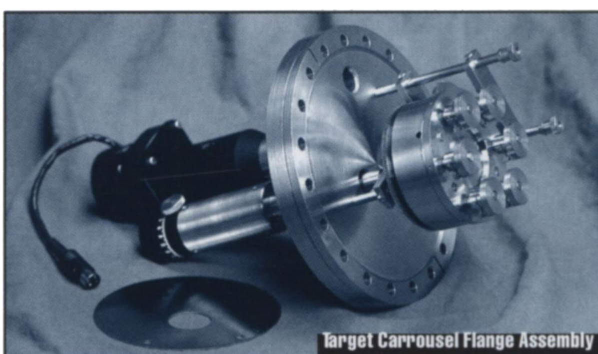

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to rapid changes in temperature. The shrinking ZrW_2O_8 would counteract the expansion of conventional materials, creating products that neither contract nor expand when heated or cooled.

Pyroelectrolysis Works Toward Cleaner Steelmaking

Donald R. Sadoway, a professor of the Department of Materials Science and Engineering at the Massachusetts Institute of Technology, is developing a new technology for the production of steel that involves zapping a molten mixture of iron ore and other materials with electricity. The principal byproduct of the new system is oxygen.

Dubbed pyroelectrolysis, the technology uses electrical energy to do chemical work. Iron oxide is fed into an electrolysis cell where it is made to dissolve in a solution of other molten oxides. An electric current is passed through the cell from one end (the anode) to the other (the cathode). At the interface of the molten oxides and the cathode, the steel is formed. The principal byproduct, oxygen, bubbles off the anode.

Carbon would be added to the process as an ingredient but it would not be used in the vast amounts as it is currently as a fuel and as a chemical reactant to extract the iron from its ore. While electrolysis used in producing aluminum involves the anode made of carbon, that is not the case here.

Pyroelectrolysis may be able to produce higher-purity alloys. The carbon used in the current steelmaking process contains sulfur, a contaminant that leads to a lower-quality metal. Sadoway's technology would eliminate the steps currently in place to remove sulfur from steel, saving energy and money.

Embedding Micromachines in Silicon Trenches Allows Integration with Silicon Chip

Continuing their work in microengine fabrication (see "Silicon Microengine Turns Gears, Operates Shutter," *MRS Bulletin* **XX**, December 1995, p. 10), researchers at Sandia National Laboratories have put together micromachines along with a smart integrated circuit on individual silicon chips. The compact design, made possible by sinking the motors in tiny etched trenches, enables the fabrication of electromechanical systems on a chip.

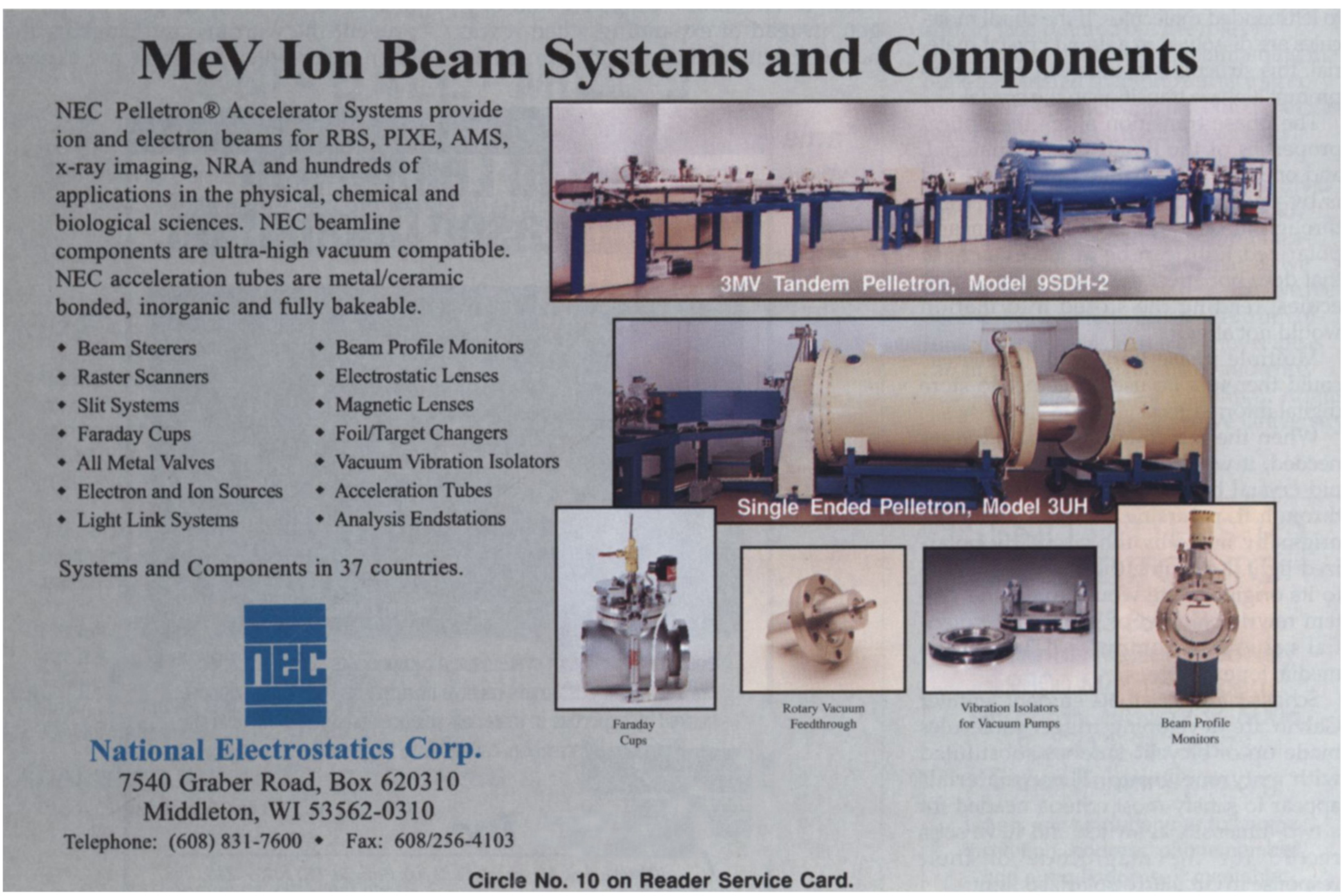
The process etches tiny trenches in silicon chips and fabricates the machines within these depressions. The machines heat-treated, are then submerged in a tiny hardening sea of silicon dioxide.

"If you first sink the machine in a trench and then fill in around it, in effect you've recreated a pristine wafer for doing electronic processing," said Steve Montague, inventor of the approach.

The hardened silicon dioxide recreates a level chip surface upon which circuitry is fabricated by photolithography. Removal of the silicon dioxide at the end of the process frees the microengines.

Circuits fabricated only microns from a machine eliminate ghost signals—parasitic currents—created by excess electrical capacitance in long connecting wires.

"Without this interference, by applying a mechanical load you can measure the capacitance change in the drive gear teeth as they move in and out," said Sandia engineer Ernest Garcia. "Then you know how



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fast the machine is moving. The sequence allows you to understand velocity."

Previously, the difficulty with joining a microcircuit to a micromachine on a silicon chip had been that aluminum circuit interconnectors, if formed first, melted when the micromachines were heat-treated. When micromachines were fabricated first, their elevation above the chip surface created bumps that distorted the process of etching accurate microcircuits.

YH_3 and LaH_3 Change from Mirror to Transparent Window

Thin films of yttrium and lanthanum coated with a layer of palladium and exposed to hydrogen change from metallic to semiconducting behavior and from a reflective to a transparent sheet. "Yttrium hydride, for example, changes from a shiny mirror to a yellow, transparent window," said researchers from the Faculty of Physics and Astronomy, Vrije Universiteit in the Netherlands. Their article, published in the March 21 issue of *Nature*, describes the reversible optical properties of yttrium (YH_3) and lanthanum hydrides (LaH_3).

The researchers evaporated a 500-nm-thick yttrium film under ultrahigh vacuum conditions and coated it with a 5–20-nm-thick layer of palladium. Upon exposure to hydrogen at room temperature, the material transformed from a reflecting pure yttrium film into a partially reflecting dihydride, then into a transparent yellowish film. After measuring various characteristics, including electrical resistivity and optical transmission, the scientists concluded that the switch from reflectivity to transparency correlates with electrical properties of the material.

Roll-Textured Buffered Metal Forms Foundation for High-Current Superconducting Wire

Researchers at Oak Ridge National Laboratory have produced a roll-textured, buffered metal, superconducting tape with a critical current density of 650,000 A/cm^2 at 77 K. Researchers have developed a method for fabricating the wire by employing the process of rolling-assisted biaxial textured substrates (RABiTS). The process conditions the substrate upon which superconductors can be formed and provides the underlying foundation for the wire. RABiTS enables the superconducting materials to have a high degree of grain alignment in all directions along the wire, allowing for more efficient current flow through the superconductor.

The nickel base metal tapes are textured using rolling and heat treatment procedures. No further surface treatments, such as polishing, are used. A buffer layer technology, developed specifically for these substrates, is used to provide a chemical barrier between the nickel and the superconductor while maintaining the texture. The high-temperature superconductor yttrium-barium-copper-oxide (YBCO) is then deposited on the RABiTS conditioned surface by pulsed-laser deposition. The high-current sample was 3 mm wide and 15 mm long.

"These substrates will enable the next generation of high-temperature superconducting wires to be used in transmission cables, transformers, current limiters, motors, and generators," said Robert Hawsey, director of ORNL's Superconductivity Technology Center.

Sealed Metal Mold Heating Process Speeds Production of Aerogels

Researchers at Lawrence Livermore National Laboratory have developed a heating technique that reduces the production time of silica aerogels from 25 hours to about one hour.

This technique injects the chemical mixture of water with ammonia, alcohol, and methoxysilane into a sealed metal mold. These molds, which vary according to the aerogel shape desired, are placed within heating coils that achieve the same temperatures and pressures as autoclaves, instruments that, over hours, slowly remove liquids at 280°C and 80 bars (about 1,200 pounds per square inch of pressure) from the gel without cracking the material's delicate structure.

"The heating process can go much faster in a mold because the mold fully contains the aerogel," said physicist Larry Hrubesh, co-inventor of the process. "In an autoclave, at least one side of the mold is open, so if the aerogel is heated too quickly, it will push out of the mold and crack."

Hydrogen Produced in Metallic Form

Researchers at Lawrence Livermore National Laboratory have converted hydrogen into a metallic form. In an article published in the March 11 issue of *Physical Review Letters*, researchers Sam Weir, Art Mitchell, and Bill Nellis described the use of a two-stage gas gun to create shock pressure on a target containing liquid hydrogen cooled to 20 K. By measuring the electrical conductivity, they found that metallization occurs at a temperature of 3000 K. Because of the high temperature, the hydrogen was a liquid. The intense pressure lasted less than a microsecond.

In the first stage of the two-stage gas gun experiment, gunpowder is used to drive a piston down the pump tube, compressing hydrogen gas ahead of it. Squeezed to sufficient pressure, the hydrogen breaks a rupture valve and accelerates a projectile down the second stage barrel at velocities up to 7 km/s.

The projectile generates a strong shock wave on impact with an aluminum sample container, which is cooled to 20 K. Entering the liquid hydrogen, the shock pressure first drops, then reverberates many times between parallel sapphire anvils until the final pressure, density, and temperature are reached. This reverberation produces one-tenth the temperature that would be created by a single shock to the same pressure. The temperatures achieved keep hydrogen in the form of molecules, rather than letting molecules break into atoms. Because the experiments were done at higher temperatures than originally predicted, the results suggest that the metallization pressure of hydrogen is temperature-dependent.

A trigger pin in the target produces an electrical signal when it is struck by the initial shock wave; this signal is used to turn on the data recording system at the proper moment. The electrical conductivity of the hydrogen shock is then measured to determine if metallization has occurred.

The researchers found that in the metallic phase, even if just for an instant before the sample was destroyed, the hydrogen molecules appeared to ionize, but remain paired. That is, they formed a paired metal where the ions pair up and cannot be broken apart. In other metals, the crystal structures are usually based on single ions. But that appears not to be the case with hydrogen.

The metallization events occurred for such a brief period of time, and in such a manner, that questions about its superconducting properties and retention of metallic form following pressure removal could not be answered.

The study of hydrogen as a metal is significant for condensed matter physics. As a low-temperature liquid, it is an insulator, but as a high-density metal, it could be a superconductor, which could carry electricity with no or little resistance. At high temperatures, it could be used in applications where heat is generated, such as in controlled fusion for an abundant energy supply. The understanding of dense hydrogen would help in understanding the dynamics of Jupiter, for example, which is thought to have an abundant supply of hydrogen in metallic form.

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"Hydrogen is a major player in the universe," said Neil W. Ashcroft, a Cornell physicist who speculated on this case. "It's very basic to physics and astrophysics. Understanding it in its metallic phase is critical to understanding planetary interiors." If this notion of its properties is correct, then astrophysicists may have to change their models of the internal constitution of Jupiter, and thus, the basic ideas about how gaseous giant planets in general formed.

Waymouth to Receive NSF's 1996 Waterman Award

Robert Waymouth, associate professor of chemistry at Stanford University, will receive the Alan T. Waterman Award of the National Science Foundation for his work with polymers. The award includes a $500,000 grant over three years to pursue any line of research.

Waymouth's honor is based partly on his work discovering ways to make polymers. In his nomination, John Brauman, chair of the department of chemistry, described the research as "[work that] has defined an extremely promising new interdisciplinary area at the interface of organometallic and polymer chemistry. This work is distinguished by creativity in developing new polymerization reactions as well as unusually deep and thoughtful investigations into the mechanisms by which polymers form."

One part of that work has drawn exceptional attention from fellow chemists and from industry. Waymouth has devised a way to make catalysts that change their behavior while they work. "It's hard enough to design a catalyst that does one thing very well," Waymouth said, "but we thought we would try to get one to switch between doing two different things."

He and his graduate students tested the idea by making polypropylene. They made a catalyst that switches back and forth between two shapes at a rate slightly slower than the speed at which each link in the developing polypropylene chain is formed. The reaction knits in a long, thin fiber that is alternately stiff and flexible.

The fiber turned out to be an unusual form of polypropylene, which Waymouth calls "thermoplastic elastomers." They are nearly as low cost and as meltable (thus recyclable) as ordinary polypropylene plastic, but they can be as elastic as rubber.

Waymouth said he will use the Waterman Award funds to investigate the properties of the catalysts and the new family of polymers. "We've discovered them; we know that they work. Now the exciting thing is to find out how the catalysts work, and why the polypropylenes have some of the properties they do."

Waymouth graduated summa cum laude from Washington and Lee University in 1982 with dual degrees in mathematics and chemistry. He received his doctorate in 1987 from the California Institute of Technology, and came to Stanford University as assistant professor in 1988.

The Waterman Award is named for the late Alan T. Waterman, founding director of the National Science Foundation. The annual award was established by Congress in 1975 to recognize an outstanding researcher age 35 or younger in any field of science and engineering. At an early stage in their careers, the award recipients are recognized for "outstanding capability and exceptional promise for significant future achievement in their fields." □

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