APPENDIX E: MEDIA PUBLICITY MATERIALS

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Breakthroughs in capacity, power consumption set to revolutionize photonics

For years, organic electro-optic polymers have held the promise of vastly improving technologies such as communications, data processing and image displays. Now it appears scientists are on the verge of breakthroughs that will bring dramatic progress in materials, as well as the devices in which they are used, setting the stage for a virtual revolution.

Simply put, electro-optic polymers are being used to make devices that take information that typically has been transmitted electronically and transfer it to optical systems that use light. The latest developments will affect not just how much information can be sent at one time but also the power required to transmit the information.

The newest materials have made possible something called wavelength division multiplexing, a process that can separate a beam of light into perhaps 100 different colors and impose as much as 50 gigabits of information on each color. At that rate, a beam of light could transmit 5 terabits — or about 625 gigabytes — of data per second, and could move data equivalent to what is in the Library of Congress in about 30 seconds.

The capabilities of the most recently developed materials are about five times greater than those of standard lithium niobate crystals, said Larry Dalton, a University of Washington chemistry professor and director of the Science & Technology Center on Materials and Devices for Information Technology Research. He will discuss some of the center's work during a topical lecture Friday at the American Association for the Advancement of Science meeting in Seattle.

Dalton also said the newest materials require less than one-fifth the voltage (less than 1 volt) needed for lithium niobate, the best naturally occurring material for transferring data from electronic to optical transmission and for many years the industry standard.

"What this shows is that people have done far better than nature could ever do in this process," Dalton said. "It's a perfect example of nanoscopic engineering. The reason we're seeing improved performance is the rational design of new materials with new properties."

The newest materials represent a nearly fivefold improvement in capability in just four years. At that rate, long before the end of this year material capabilities will reach benchmarks set for 2006 in the original National Science Foundation proposal for the center. Even more ambitious goals have been set by the Defense Advanced Research Projects Agency, a major supporter of electro-optic materials research.

The center (http://stc-mditr.org), which has seven core research partners and involves 13 universities, was established at the UW two years ago by the National Science Foundation. Besides NSF support that could reach $40 million over 10 years, the center has been championed by a number of public and private agencies that could push its total support to nearly $100 million over 10 years.

The center's work will be the subject of two AAAS symposia, 21st Century Photonics, at 9:30 a.m. and 2:30 p.m. Sunday. Alvin Kwiram, a UW chemistry professor and the center's executive director, organized the sessions and presenters include Dalton; Alex Jen, a UW professor of material science and engineering; and Bruce Robinson, also a UW chemistry professor. Other presenters are from the University of Southern California; the University of California, Santa Barbara; Princeton University; the University of California, Berkeley; the California Institute of Technology; Cornell University; the Georgia Institute of Technology; Pacific Northwest National Laboratories; and Lockheed Martin Advanced Technology Center.

Discussions will cover recent advancements that are making possible technology that until recently was only a fanciful vision, Dalton said.

For instance, components now can be made so small and power efficient that they can be arranged in flexible, foldable formats yet experience no optical loss or change in power requirements until the material is wrapped around a cylinder as tiny as 1.5 millimeters, a little bigger than a paper clip.

Such materials can be used to create space-based phased array radar systems for surveillance and telecommunications applications. Each face of a phased array typically has thousands of elements that work in a complex interdependence. A major advantage of the new material is that the entire radar system can be launched in a very compact form, then unfurled to its full form once it reaches orbit, Dalton said. Deployment costs can be greatly reduced because of low power requirements and the much-reduced weight of the material being sent into space. Techniques to mass-produce the tiny foldable components, which should reduce costs even further, are being developed with the California Institute of Technology, he said.

The newest materials have immediate applications in a number of other technologies as well, Dalton said. For instance, photonic elements can make it possible for a cellular telephone to transmit a large amount of data with very low power requirements, allowing a device that is very efficient to be made very compact. Similarly, the materials can bring greater efficiency and affordability to optical gyroscope systems, commonly used in aircraft navigation but also adaptable for other uses if costs are low enough.

In addition, photonics can be used instead of coaxial cable to manufacture a variety of components in satellites, reducing the weight of the components as much as 75 percent and so greatly cutting the overall weight of a satellite.

"The cost of getting something up into space is horrendous because of weight, so anything that reduces weight and power requirements is of immediate importance," Dalton said.

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MEDIA NOTE: This release is embargoed the beginning of the Symposium at "21st Century Photonics [part 2]", which begins at 2:30PM Pacific Time on Sunday February 15, 2004.

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Georgia Institute of Technology Research News

3D fabrication technique uses light-activated molecules to create complex microstructures

A three-dimensional microfabrication technique that uses a unique class of light-activated molecules to selectively initiate chemical reactions within polymers and other materials could provide an efficient way to produce complex structures with sub-micron features.

Georgia Institute of Technology Professors Seth Marder (left) and Joe Perry pose with laser equipment they use to write complex 3D structures in polymers and other materials.

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Known as "two-photon 3D lithography," the technique could compete with existing processes for fabricating microfluidic devices, photonic bandgap structures, optical storage devices, photonic switches and couplers, sensors, actuators, micromachines -- and even scaffolds for growing living tissue.

Georgia Institute of Technology Researchers Seth Marder and Joseph Perry will describe the technique February 15 at the annual meeting of the American Association for the Advancement of Science (AAAS).

"We have developed a disruptive platform technology that we believe will provide broad new capabilities," said Marder, a professor in Georgia Tech's School of Chemistry and Biochemistry. "We believe this technique provides a real competitive advantage for making complicated three-dimensional microstructures."

The technique uses a family of organic dye molecules known as Bis-donor phenylene vinylenes that have a special ability to absorb two photons of light simultaneously. Once excited, the molecules transfer an electron to form a simple acid or a radical group that can initiate a chemical reaction -- such as polymer cross-linking or ion reduction.

By adding small concentrations (0.1 percent) of the molecules to a resin slab containing cross-linkable acrylate monomer, for example, researchers can use a focused near-infrared laser beam to draw patterns and initiate cross-linking reactions only in material exposed to the light. The reactions can make that portion of the slab insoluble, allowing the remainder to be washed away to leave a complex three-dimensional structure.

The researchers have demonstrated the ability to create both positive and negative resists using two-photon activated reactions to alternatively create soluble or insoluble 3D patterns. Beyond polymers, Perry and Marder have demonstrated the fabrication of tiny silver wires from patterns written in materials containing silver nanoparticles and ions.

The molecules developed by Marder and Perry are hundreds of times more efficient at absorbing two photons than previous photoactive materials. That efficiency allows them to write 3D patterns in polymer slabs that are typically 100 microns thick, at light intensities low enough to avoid damaging the materials.

The laser writing process takes advantage of the fact that the chemical reaction occurs only where molecules have absorbed two photons. Since the rate of two-photon absorption drops off rapidly with distance from the laser's focal point, only molecules at the focal point receive enough light to absorb two photons.

"We can define with a very high degree of precision in the x, y and z coordinates where we are getting excitation," Marder explained. "Using 700-nanometer light, the patterning precision can be about 200 nm across by 800 nm in depth."

By scanning the laser in the sample while turning the laser off and on, Perry's group has created a variety of structures, including objects with moving parts like gears and chains. Three-dimensional structures produced by the technique could be used as molds or templates for mass-producing other structures through simple stamping processes. The technique could also be used to create textured surfaces on which tissues can be grown, or optical elements such as photonic band-gap structures used to manipulate light.

For producing 3D microstructures, the simple two-photon technique could compete with complex multi-step fabrication processes that use lithography, etching and layering technologies borrowed from the microelectronics industry. However, the two-photon technique can produce only one structure at a time, while the microelectronics-based processes simultaneously generate hundreds or thousands of identical structures.

Right now, that makes the new system more suitable for adding specialized 3D structures to microsystems, prototypying new structures or making molds than for producing entire systems, notes Perry, also a professor in Georgia Tech's School of Chemistry and Biochemistry. Producing each structure now requires about 25 seconds, but increases in speed could make mass-production feasible.

"We are working to integrate the technologies and develop a system that should be able to operate at a thousand times the throughput of the current system," he said. "A single 3D fabrication system should be able to generate about a million individual device structures per day. With a production facility using a number of fabrication systems, there is potential for certain types of mass production."

The researchers envision tabletop fabrication machines that would use a computer-generated design system to laser write the desired structures. A cartridge containing the polymer film would then be removed for chemical development.

To move their technologies into the commercial world, Marder and Perry have helped form a company known as Focal Point Microsystems. The firm has licensed the technologies, which were developed when the scientists worked at the California Institute of Technology and the University of Arizona before joining Georgia Tech last summer.

In collaboration with researchers at Arizona and Cornell, Marder and Perry have also been examining the fluorescent properties of the materials for possible applications in biological imaging. The molecules also have properties that are of interest for photodynamic therapy, which would use light to destroy cancer cells.

For the future, Marder and Perry hope to continue improving their dyes, increasing the resolution of the laser writing process, expanding their family of materials – and better understanding the process. "The scientific challenges are getting things smaller, writing faster and increasing the number of materials in which you can write," Perry said.

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CORNELL NEWS

Cornell-developed tools to guide and switch light could lead to photonic microchips and practical home fiber-optic lines

EMBARGOED UNTIL SUNDAY, FEB. 15, 2004, AT 2:30 P.M. PST, 5:30 P.M. EST

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SEATTLE -- A Cornell University researcher is developing techniques for making photonic microchips -- in which streams of electrons are replaced by beams of light -- including ways to guide and bend light in air or a vacuum, to switch a beam of light on and off and to connect nanophotonic chips to optical fiber.

Michal Lipson, an assistant professor at Cornell, in Ithaca, N.Y., described recent research by the Nanophotonics Group in Cornell's School of Electrical and Computer Engineering at the annual meeting of the American Association for the Advancement of Science (AAAS) in Seattle on Sunday, Feb. 15. Her talk was part of a symposium on "21st Century Photonics."

Lipson suggested that one of the first applications of nanophotonic circuits might be as routers and repeaters for fiber-optic communication systems. Such technology, she added, could speed the day when home use of fiber-optic lines becomes practical.

Researchers already have built nanoscale photonic devices in which wires are replaced by square waveguides that confine light by total internal reflection. This works only in materials with a high index of refraction, such as silicon, where there is a loss of light intensity and sometimes distortion of pulses. Lipson described a way to guide and bend light in low-index materials, including air or a vacuum. "In addition to reducing losses, this opens the door to using a wide variety of low-index materials, including polymers, which have interesting optical properties," Lipson said.

Using equipment at the National Science Foundation-supported Cornell Nanoscale Facility, Lipson's group has manufactured waveguides consisting of two parallel strips of a material with a high refractive index placed about 50 to 200 nanometers apart, with a slot containing a material of much lower refractive index. (A nanometer is about the width of three silicon atoms.) In some

devices the walls are made of silicon with an air gap, and others have silicon dioxide walls with a silicon gap. In both cases, the index of refraction of the medium in the gap is much lower than that of the wall, up to a ratio of about four to one.

When a wavefront crosses two materials of very different refractive indices and the low-index space is very narrow in proportion to the wavelength, nearly all of the light is confined in the "slot waveguide." Theory predicts that straight slots will have virtually no loss of light, and smooth curves will have only a small loss. This has been verified by experiments, Lipson reported.

Slot waveguides can be used to make ring resonators, already familiar to nanophotonics researchers. When a circular waveguide is placed very close to a straight one, some of the light can jump from the straight to the circular waveguide, depending on its wavelength. "In this way we can choose the wavelength we want to transmit," Lipson said. In fiber-optic communications, signals often are multiplexed, with several different wavelengths traveling together in the same fiber, each wavelength carrying a different signal. Ring resonators can be used as filters to separate these signals, she suggested.

Like the transistor switches in conventional electronic chips, light-beam switches would be the basic components of photonic computers. Lipson's group has made switches in which light is passed in a straight line through a cavity with reflectors at each end, causing the light to bounce back and forth many times before passing through. The refractive index of the cavity is varied by applying an electric field; because of the repeated reflections, the light remains in the waveguide long enough to be affected by this small change. Lipson is working on devices in which the same effect is induced directly by another beam of light.

Connecting photonic chips to optical fibers can be a challenge because the typical fiber is vastly larger than the waveguide. It's like connecting a garden hose to a hypodermic needle. Most researchers have used waveguides that taper from large to small, but the tapers typically have to be very long and introduce losses. Instead, Lipson's group has made waveguides that narrow almost to a point. When light passes through the point, the waveform is deformed as if it were passing through a lens, spreading out to match the larger fiber. Conversely, the "lens" collects light from the fiber and focuses it into the waveguide. Lipson calls this coupling device "optical solder." Based on experiments at Cornell, the device could couple 200-nanometer waveguides to 5-micron fibers with 95 per cent efficiency, she reported. It can also be used to couple waveguides of different dimensions.

The method of coupling nanoscale waveguides to optical fiber is described in a paper, "Nano-taper for Compact Mode Conversion," published in *Optics Letters (* August 2003). Slot waveguides are described in "Guiding and Confining Light in Void Nanostructures," accepted for publication in *Optics Letters*. Some of the work has been done in collaboration with researchers working under Alexander Gaeta, Cornell associate professor of applied and engineering physics. The Cornell nanophotonics group web site is http://nanophotonics.ece.cornell.edu/ .