

APPENDIX D. MEDIA PUBLICITY MATERIALS

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Written by John Manuel

Innovative Technologies: Organic Solar Cells

Photovoltaic cells that convert sunlight into electricity have been around for decades, yet their commercial use has been largely limited to applications where conventional electric power is difficult or impossible to provide, such as lighting of road signs and offshore buoys. The problem is primarily economic--although sunlight is free, the high cost of manufacturing traditional silicon-based solar cells has limited their penetration into markets where coal, nuclear, and other nonrenewable sources currently provide more economical energy. Researchers at the Georgia Institute of Technology have developed a new type of solar cell that may someday change that equation.



Solar sensation. New thin-film technology offers promise in converting solar energy into electricity.

image: Nicole Cappello/Georgia Tech

Bernard Kippelen, a professor in the Center for Organic Photonics and Electronics and the School of Electrical and Computer Engineering at Georgia Tech, is leading studies into the use of pentacene as a medium for converting sunlight to electricity. Pentacene, a compound of carbon and hydrogen, can form a crystalline film in which molecules assemble in an ordered pattern. This makes the compound more conducive to the flow of electricity than the disordered organic compounds that have been tested in the past for possible photovoltaic applications. Improved conductivity leads to higher efficiency, and if that quality can be combined with low cost of manufacture and ease of use, the material holds great promise.

In an article published in the 29 November 2004 issue of *Applied Physics Letters*, Kippelen and fellow research scientists Seunghyup Yoo and Benoit Domercq describe their tests of an organic film made of pentacene combined with a form of carbon known as C₆₀. The organic layers and an electrode were sequentially deposited onto indium-tin oxide substrates. Broadband illumination was provided by a lamp, photocurrent was measured under varying light

spectrums, and conversion efficiencies (the amount of light converted into electricity) were calculated.

The team was able to convert solar energy into electricity with 2.7% efficiency; in unpublished tests since then, they demonstrated power conversion efficiencies of 3.4%. Kippelen believes they will be able to reach 5% in the near future.

Commercial photovoltaic cells that employ silicon crystals are 12-15% efficient, but they are expensive to manufacture and run. Complete systems, including installation, produce electricity at a cost equivalent of 20-40¢ per kilowatt hour (depending upon scale of system and financing) versus 8-12¢ per kilowatt hour for electricity generated by conventional power plants. Kippelen says development of thin-film organic solar cells is not far enough along to estimate the costs of energy production. However, the thin-film cells could possibly be manufactured in a roll-to-roll process, significantly lowering their cost and narrowing the gap with fossil fuel-generated electricity.

Kippelen is confident that his product's unique properties will allow it to be used in applications for which silicon cells are not appropriate. Whereas silicon cells are rigid and relatively thick at 100 microns across, thin-film organic solar cells are lightweight, flexible, and less than 1 micron thick. This could open up new markets for solar energy, perhaps powering small electronic devices such as radiofrequency identification tags, MP3 players, and laptop computers. Kippelen estimates that organic solar cells are at least five years away from residential applications but could find niche low-power applications within two years.

However, thin-film solar power will need to be deployed on a much larger scale if it is to significantly improve the environment. "Small electronic devices represent a miniscule part of total energy consumption," says Tom Starrs, chairman of the American Solar Energy Society. "For any photovoltaic technology to make a significant contribution to global energy needs, it needs to be interconnected with the electrical grid, displacing power generated by coal, nuclear, and other nonrenewable sources of energy."

Written by Kim Krieger



Small wonders

What does it take to create intricate sculptures far smaller than a grain of sand? Kim Krieger meets the micro-Michelangelos

IT COULD be the world's smallest fence: a chain of five crude, squarish links is strung between posts just 40 micrometres apart. This microscopic barrier marks the threshold of a new world of fabrication.

The interlocking links of the chain would be impossible to make using conventional microfabrication techniques. Instead, they were conjured into existence by waving a magic wand – or rather, a laser beam. This method, called two-photon 3D microfabrication, is just starting to make its mark. Fast, cheap and flexible, it can create multilayered microchips, custom-designed crystals, pre-assembled propellers – tiny objects with fantastical curves, interlocking parts and 3D structures, all qualities difficult or impossible to achieve with traditional techniques. “It’s like making Frank Gehry-type buildings instead of flat

warehouses,” says Malvin Teich, an engineer at Boston University.

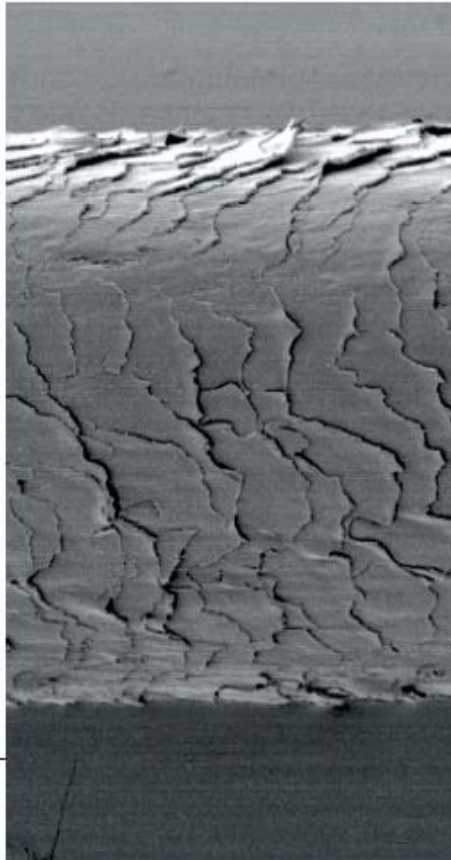
The “flat warehouses” he means are the silicon computer chips made by photolithography, today’s standard in microfabrication. Photolithography etches the circuit onto the silicon by shining ultraviolet light through a flat mask perforated with the pattern of the chip circuitry. The technique can produce multilayer constructions, by depositing successive layers of silicon and using different masks to etch each layer, slowly building up a 3D structure. But you could never build a curvy Bilbao Guggenheim in this way.

Two-photon microfabrication is a different story. “You could do this on top of a desk, if you had the right lasers,” says John Fourkas, Teich’s collaborator at the University of Maryland in College Park. In fact, Fourkas is pretty much

describing his lab, which is essentially just a big table with a laser hooked up to a computer and a few lenses. The laser scans through a drop of liquid resin on a slide, hardening the resin in a 3D pattern so that when the excess liquid is washed off it leaves behind a microscopic plastic structure.

The resin works a bit like the material in white dental fillings. When you get a filling, the dentist shines an ultraviolet light onto the mixture to fix the substance into a hard, acrylate polymer. In two-photon 3D microfabrication, the laser does essentially the same thing: energy from the beam excites molecules of a special dye, each of which then offloads one of its electrons onto a nearby acrylate molecule. That triggers a chain reaction in which the acrylate molecule grabs another acrylate molecule and passes on the electron, the second acrylate grabs a third, and so on, linking together a soup of small molecules to make a sturdy chain of plastic.

But there is a twist: a single photon from the laser doesn’t have enough energy to excite a dye molecule, but two photons have exactly the right amount. Only at the focus of the



JAN VORISEK

Bringing new meaning to the minuscule, laser sculpture can form letters just a few micrometres high

laser are the photons dense enough to allow the dye to absorb two at a time, triggering polymerisation. So the resin hardens only at the laser's focus, while the rest of the beam passes through with no effect.

This is what makes two-photon microfabrication so powerful. The beam's focus is fine enough to create details just a few tens of nanometres across, smaller than a single wavelength. The laser can focus at any depth within the transparent drop of resin, and it can scan smoothly or skip, to generate microscopic structures with separate components, including such finely wrought 3D creations as the microscopic chain. The fence was created in 2003 by Joe Perry, a chemist working with two-photon microfabrication, and Kevin Braun, then Perry's student at the University of Arizona in Tucson, to demonstrate the potential of the technique.

As well as reaching into the third dimension, this process has two more

advantages over photolithography: it is faster and cheaper. The elaborate masks required for photolithography cost tens of thousands of dollars each and require several weeks to make. In comparison, two-photon microfabrication is ridiculously cheap: you just fit an off-the-shelf laser with the appropriate software, and then the only costs are for raw materials.

"People know how to make things on the microscale, but not arbitrary things," says Fourkas. "This is the first technique that can operate on that microscale and you can make anything you want." So if you could wave a laser wand and make anything at all, what would you choose?

"Three-dimensional optical information storage," says Teich. A cube could store information much more compactly than flat CDs and DVDs, for example, perhaps holding thousands of movies instead of one or two.

"Micro-MRI probes," says Fourkas. He and his collaborators think that instead of putting the patient inside an MRI machine, doctors could put the MRI inside the patient. You could thread tiny MRI coils through a diseased heart, for example, to give a far more detailed picture than external MRI scans.

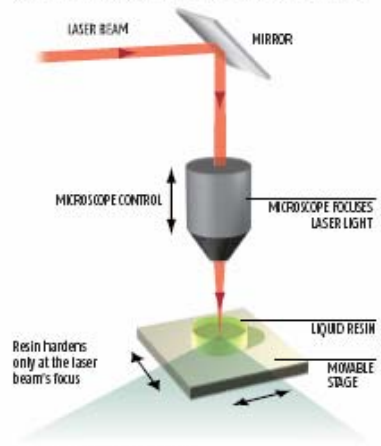
Digital light processors, scaffolding for artificial organs, microfluidic "lab on a chip" devices... all these come up on the wish lists of researchers who have seen laser sculpture in action. The polymer resin should be able to meet the physical demands of each, because the recipe is quite flexible, as long as it contains the light-sensitive dye. Metal parts or semiconductors could be plated on afterwards to make electrical circuits, and perhaps eventually whole 3D chips. Adding a third dimension to computer chips could tremendously increase their processing power.

At Focal Point Microsystems in Atlanta, Georgia, Perry hopes to turn promise into commerce. The company, founded by Perry and other researchers at the Georgia Institute of Technology, is developing a ready-made laser-machining device to sell to researchers. The next step is to take the technique beyond research. At the moment, although two-photon microfabrication is fast and cheap compared with photolithography when making one-off designs, it loses out in mass production. Once the photolithographic mask is made, the printing process can turn out

"It's like making Frank Gehry buildings instead of flat warehouses"

LASER-SCULPTING

Complex 3D structures just a few micrometres across can be built by focusing a laser into liquid resin to solidify the desired parts



Chain-link fence created by laser



thousands of components in the time it takes a laser to build up a single structure. The speed needs to increase.

One idea is to use moulds. You laser-sculpt the prototype and then form a mould around it. A single prototype can form many moulds, which can each be used again and again. You might think that micron-sized objects would be too delicate to be torn out of a reusable mould, but if the material of the mould is soft enough they won't break. Fourkas and colleagues have been experimenting with polymethylsiloxane, more familiar as bathtub caulk, which is so rubbery that it bends around just about anything without damaging it. The group has been able to cast details as delicate as micron-sized needles, as well as overhangs and cavities.

Commercial applications may be only a few years away. And after the architectural revolution of microfabrication, 2D microdevices will probably seem as primitive as a flat-roofed shack. ●

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Hooked On Photonics

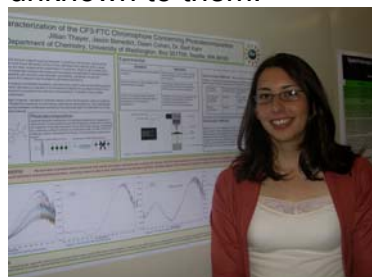
Summer Program Opens Doors For Undergrads

By Stephanie Cartier

New students to any school face a barrage of challenges, but if the new student is making the transition from a small community college to a major research institution, the challenges can be overwhelming. Students might be hesitant in the lab, insecure about their abilities and feel lost in a large class environment. But programs like Research Experiences for Undergraduates (REU) can help ease the transition and break down perceived barriers for students with little or no research experience.

Through funding from the National Science Foundation (NSF), undergraduates who might otherwise not have lab experiences are able to work side-by-side with researchers at several well-known universities nationwide. It's all happening at the Center on Materials and Devices for Information Technology Research (CMDITR), which is based primarily at three university campuses: University of Washington (UW), the center headquarters; the University of Arizona; and Georgia Institute of Technology. All three campuses have hosted summer programs, where CMDITR coordinators are working to create new opportunities for interdisciplinary, hands-on education in the hopes of facilitating a more diverse and better trained workforce. At the UW over the summer, CMDITR sponsored an REU program called "Hooked on Photonics."

Photonics uses light to control, transmit, and manipulate information. Research in this field is expected to lead to faster communication over new optically based networks. And while not every student who participates in the ten-week summer program will go on to pursue a graduate degree in photonics, those who participate say it's a valuable experience because it helps them build confidence and explore options previously unknown to them.



"We wanted to get the people who wanted to come in and didn't know that much about research," says Phil Reid, UW chemistry professor. Reid is the recipient of several teaching awards, including a Career Award from the NSF. His students say he has a knack for explaining really difficult concepts in a way that is easy to understand. And REU participants benefit from Reid's teaching expertise. "They can really enhance their education over and above what they have envisioned it to be: simply going to class, going to

lecture, doing courses."

But even if students learn about the benefits of hands-on research opportunities, they could face other challenges. Reid points out that coming to a large university could present a challenge to a student nervous about knocking on a professor's door. One of the goals of the program is to facilitate interaction between students who might otherwise remain anonymous in a large classroom setting. "This gives them a way, in a low-risk environment, to come in and experience that part of the mission and see themselves as part of the research that goes on in the university," says Reid.



Participant Jillian Thayer will start undergraduate work at the UW this fall after completing two years of community college in Bremerton, Wash. She says the program has provided valuable insights about graduate programs. "Working with the graduate students has been incredibly insightful," says Thayer. "I've loved coming in and doing research for so many hours a day, and they get to do that all the time. So I've really been turned on to the idea of graduate school," Thayer says.

Stacy Oliphant is another student in the program who says she's seen more opportunities this summer than she would have at the community college level. "At first I didn't really think of going on more than an associate's degree, but the better education you have, the more possibilities are open." She says the confidence and ability to work on her own have proven to be some of the greatest lessons from this summer's session. "I was a little nervous, of course, at first when she [my mentor] said, 'Okay, go ahead and do it,' and I didn't want to break anything, I didn't want to mess anything up." Two and a half months later, this same student is able to articulate the work she has done.

Graduate student mentor and doctoral student Kristin Wustholz says the change in the students is noticeable. "They're much more talkative; they talk amongst themselves about the projects, and they're just more able to communicate about the project, and they're more outgoing with each other and within their lab groups, which is good." While the goal of the program is to get students interested in photonics, the students say the experience in the lab has been the most useful part. "I think it's interesting, and it might be nice to continue working on it, but I don't know that I'd want to do it for a living," says Oliphant.

Reid agrees, saying the more important goal is to point students in the right general direction. "At least show them the door and the way in," he explains.

Thayer, who is considering medical school, says the program has helped open her eyes to a lot of opportunities. "What I loved about this program is, as a community college student, I had the exact same opportunities as someone from Cornell University, and we're working side by side, and that was awesome to dive into something. It has served as sort of a transition between community college and university life. I think it's a really rare opportunity for community college students to get into something like this."



Stephanie Cartier is pursuing a master's degree in Technical Communication at the University of Washington.

Images:

Top: The Hooked on Photonics Summer REU Participants. From left to right: Stephen Edwards, Greg Winchell, JoAnn Lin, Kelli Irvin, Dan Daranciang, Zerubba Levi, Stacy Oliphant, DJ Nothern, Marsha Ng, Andrew Gardner, Jillian Thayer. Photo: Kristin Wustholz

Middle: Student Jillian Thayer displays the poster she created to exhibit her summer research. Photo: Kristin Wustholz

Bottom: Phil Reid is the principal investigator for Hooked on Photonics. He has won numerous teaching awards, including a Career Award from the NSF. Students say he makes difficult concepts easy to understand. Photo: Phil Reid

Study Shows Thermal Dependence of Water Bridges

Capillaries of water can affect friction at the nanoscale

Atlanta (September 26, 2005) — “Keep cool to reduce friction” might be the advice given designers of nanoscale machinery by researchers who have just completed a study of factors influencing the formation of “water bridges” – capillary connections that can glue surfaces together, giving rise to friction forces.



Researchers Elisa Riedo and Robert Szoszkiewicz demonstrate how they used an atomic force microscope (AFM) to study how water bridges form at the nanoscale.

When surfaces touch in a humid environment, moisture forms water bridges, or capillaries, between them. On familiar size scales, this process – known as nucleation – helps hold sand castles and wet concrete together, and is critical to the formation of clouds. But sometimes these structures can be less helpful, causing friction sufficient to slow or even stop nanoscale machinery – or in food processing, creating large clusters of sugar, salt, baby cereals or coffee.

By studying the frictional forces acting on an atomic force microscope (AFM) tip drawn across a glass surface, researchers at the Georgia Institute of Technology have demonstrated for the first time that the formation of these capillaries is thermally activated. Their study suggests that it may be possible to reduce the adhesion between surfaces by reducing temperatures and putting nanoscale surfaces into motion before the water bridges have time to form.

“When you move very slowly, there is time for a capillary to form at each tiny bump or asperity in the surface,” explained Elisa Riedo, an assistant professor in Georgia Tech’s School of Physics. “But when you move faster, you have fewer capillaries. If you go fast enough, the capillaries do not have time to form.”

Understanding the relationship between nucleation time and temperature could be crucial to the designers of very small devices that must operate in the presence of moisture, as well as to the food processing industry. “Since formation of the capillaries affects friction and adhesion between particles, if we understand this relationship, we can understand how small particles and nano-surfaces glue together,” she noted.



Researchers Elisa Riedo and Robert Szoszkiewicz study data from their atomic force microscope (AFM) to determine the relationship between temperature and the formation of water bridges.

A report on the research, which has been sponsored by the National Science Foundation and the Petroleum Foundation, was published in the journal *Physical Review Letters* on September 23rd.

Experimentally, Riedo and her postdoctoral collaborator Robert Szoszkiewicz used an AFM with specially-crafted ball-shaped tips that had diameters ranging from 40 to 100 nanometers. That provided a multi-contact area of approximately 30 square nanometers.

While maintaining a constant humidity of about 40 percent, they moved the tip across a slightly rough glass surface that had irregularities approximately one nanometer high. While the tip was moving, they recorded the resistance to motion – measured in piconewtons or nanonewtons – while varying the temperature and velocity.

By charting their data, they saw evidence that the friction measured was directly related to temperature, suggesting the growth of capillary structures increases as temperature increases. “The more energetic the water molecules are, the more likely it is that they will form capillaries,” said Szoszkiewicz. “We found that nucleation times grow exponentially with the inverse of temperature.”

The researchers found that the nucleation times of nanoscopic capillaries increased from 0.7 milliseconds to 4.2 milliseconds when the temperature decreased from 332 to 299 degrees Kelvin – which is approximately room temperature.

“To form water bridges, molecules need to overcome an energy barrier. The thermal energy can provide the energy they need, however, it takes time for these bridges to form,” Riedo noted. “The longer the surfaces are together, the stronger the contact will be because more bridges can form.”



Researchers Elisa Riedo and Robert Szoszkiewicz demonstrate how they used an atomic force microscope (AFM) to study how water bridges form at the nanoscale.

When surfaces come close together, several processes can occur, Szoszkiewicz said. After contact, moisture naturally adsorbed on the surfaces – along with water molecules from the air – will concentrate close to the true contact point because of diffusion. Some initial water bridges will then form between contacting asperities.

When objects move close together but don't touch, a different process occurs. Moisture adsorbed on each surface may coalesce, and because of attractive forces, jump together, forming a water bridge. At a given temperature, this nucleation process will differ for each surface depending on its ability to adsorb moisture. Newly formed capillaries then act as water sinks, attracting more water molecules because pressure inside the capillary bridge is lower than the pressure outside it. The process continues to a point at which an equilibrium capillary bridge is formed.

“The question we considered was what would be the dominant phenomenon and what would be the time scale for both phenomena,” Szoszkiewicz said. “We have experimentally demonstrated that with nano-rough surfaces, nucleation will be dominant.”

Beyond applications to atmospheric science, the food industry and nanoscale sliding machinery, the findings suggest another way to control ink flow in dip-pen nanolithography. In that process, ink flowing from an AFM tip is used to write nanoscale patterns that could be useful in such processes as semiconductor lithography.

“In this case, you might use the temperature dependence to increase the velocity of the ink flow, decrease it, or make the flow improbable,” said Riedo. “There are a lot of implications for the technology. Each of the materials involved will have its own properties regarding velocity and how rapidly it forms capillary bridges.”

The researchers also measured the size of energy barrier required for water molecules to nucleate. “This energy was predicted by theoretical models using classical thermodynamics, and it matched really well with our experiments,” said Riedo.

The researchers hope the information they provide will help engineers deal with capillary forces in a more efficient way. Because water is ubiquitous, more information is needed about how it behaves at the nanoscale.

“Water is of crucial importance everywhere in our world – in biology, earth sciences, atmospheric sciences and industrial processes,” Riedo noted. “From a fundamental point of view, it is difficult to do theoretical models of water. But there is a huge interest in this from both theoretical and technological standpoints.”