John A. Rogers

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To: Nano Faculty :
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View from the trenches

Moving any innovation from the laboratory to the marketplace is a complex process. In the case of nanotechnology, innovators will have to tackle additional manufacturing and physical distribution challenges in order to bring products to consumers. Even if one organization could tackle the challenge on its own, doing so would be less efficient and effective than developing partnerships to access the diverse capabilities required to penetrate the marketplace.

We believe that the development of effective strategic relationships between universities, startups, and incumbents will be one of the key enablers for the emerging nanotechnology industry and will accelerate benefit of these innovations for the public at large. In light of that, we are enthusiastic to announce a partnership with the Chicago Chapter of the CDMA to provide coaching for a few nanotech start-ups in search of strategic partnerships with Fortune 500 firms. This coaching should be extremely valuable to those of you hoping to present at NanoCommerce 2003. More details can be found in the events section below.

I would like to thank both Roman Salij for his help in getting this issue out the door as I could not have done it without him, given that I am in Europe on the Nanotechnology Trade Mission.

As always, please send us your feedback and ideas for stories you think will be relevant to our audience.

Best,
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Feature Story

UIUC group rubber-stamps nanofab science
by John D. Schrock

You might not think of rubber stamps as cutting-edge technology. But Dr. John Rogers, Jana Zaumseil, Lynn Loo, and Matt Meitl at the University of Illinois, Urbana-Champaign, are using them to fabricate advanced nanostructures, including electronic circuits, pipes for transporting fluids, and sub-wavelength optical lattices. And they re doing it without expensive photolithography tools or immaculate clean rooms.

The rubber-stamp technique, dubbed nanotransfer printing (nTP), is remarkably similar to that used by bankers, government bureaucrats, and nightclub ID checkers. But instead of pressing ink onto loan applications, tax forms, and backs of hands, the Rogers group presses nanoscale patterns of gold onto a foundation of gallium arsenide.

"We're interested in how to deposit materials on stamps and then use specialized surface chemistry to transfer them from the stamps to some substrate just by contact, he says.

Rogers believes the research produced by his group will enable a host of advanced applications, including flexible electronic devices fashioned from plastic and three-dimensional nano-lattice structures that clean up signals in advanced telecommunications networks.

On the surface

Getting the surface chemistry right was one of the trickier aspects of the research, according to Rogers. A key component of the nTP technique is the self-assembled monolayer (SAM), a molecular finish that coats the substrate and bonds with the ink from the stamp, forming a chemical bridge between the two.

When printing with gold, a layer of dithiol molecules is first deposited on a substrate of gallium arsenide. When the gold film on the stamp touches the surface of the dithiol monolayer, a chemical covalent bonding occurs. We designed the stamp so there isn't a similar strong bond with the gold, says Rogers, so you put the stamp in contact with the SAM, and the gold transfers.

As with everyday rubber stamps, the geometry of the nTP stamp transfers onto the substrate. The result: a gold pattern that mirrors the relief pattern of the stamp.

The Rogers team also developed procedures for coating the rubber stamp with thin layers of metal ink without introducing cracks or other defects. Careful control of deposition conditions and stamp chemistry allowed the team to overcome the cracking problem.

"We've been able to solve both those problems," says Rogers. The adhesion we get is very good.

Going soft

The rubber-stamp approach known as soft lithography overcomes several limitations encountered with conventional fabrication techniques. Photolithography, the technology used to produce Pentiums and other microprocessors, is unsuitable for making large-area and three-dimensional devices. Another technique, electron-beam lithography, employs concentrated streams of electrons to etch very small features in silicon. But it s a serial approach, like writing; and like writing, it s too time-consuming for mass production. Scanning probe techniques, which use tiny needles to physically nudge molecules, are also too slow.

Another limitation to conventional fab methods is that they often involve photoresists, developers, and other chemicals that are incompatible with materials such as plastic that would otherwise make excellent

electronic building blocks for flexible electronics and photonic systems.

Uniquely, nTP is capable of depositing a high-resolution pattern over a large area in a single step. It's also a purely additive process, so designers can deposit materials only where they want them, without resorting to chemical etching.

Master of your (tiny) domain

The nTP process begins with the fabrication of the master the plate from which the stamps are cast using conventional processes. The idea is to use conventional, high-cost lithography once, on a substrate of silicon or glass, says Rogers. From the master we generate lots of stamps, and the stamps can be used multiple times.

The stamps themselves are made from a low-cost silicone rubber material supplied by Dow Corning. To form the stamp, liquid pre-polymer is poured over the master plate. As it flows, the liquid conforms to the relief features on the plate and is allowed to dry. Baking at low temperature polymerizes the stamp. The rubber can then be pulled back without damage.

Printing with the stamp is done at room temperature and in open air, and the process is compatible with plastics and other types of materials you can't process directly with conventional lithography, says Rogers. While nTP is sensitive to dust, for many applications it s not as sensitive to individual defects as conventional microprocessor fabrication. (For example, the properties of a sub-wavelength photonic element won't change much with a localized defect.)

Research origins

The idea for nTP grew from prior research in microcontact printing, a method of stamping organic, molecular inks onto a substrate. Molecular inks tend to spread in an uncontrolled way when deposited on a surface, and this surface-to-ink diffusion limits the resolution of the pattern. When the molecular ink is replaced with a solid ink, the diffusion disappears, and the resolution is limited only by the relief features of the stamp.

"If you get the chemistry right, you can print with incredibly high resolution. As good as the very best e-beam patterning tool, which goes down to five to ten nanometers, says Rogers.

3D structures

Engineers can also use stamps to fabricate complex, three-dimensional structures, which are difficult if not impossible to make using traditional, silicon-based tools. Coating the entire relief both the raised and recessed parts with ink forms a continuous, contoured layer that can be transferred in a single step. To build a three-dimensional device, simply stack a few layers on top of each other.

Thanks to a process called cold welding, when two gold films come into contact, the diffusivity of the gold atoms is such that it blurs the interface between layers.

Cold welding has been known for some time, but has typically required high pressure and a moderate increase in temperature. "We found that if you put gold film on a rubber stamp, and the stamp is soft enough, van der Waals interactions will suck the film into incredibly good contact with another flat, gold surface, in such a way that you don't need to apply pressure or increase the temperature at all, Rogers explains.

Cold welding forms a true chemical weld, with no discernable separation between the planes. And because the stamp is soft, many layers can be deposited without disturbing the structure of the underlying layers.

Focus is on new capabilities

Rogers says his team is looking to supplement rather than replace current techniques for making computer chips: "Our aim not so much to replace the highly engineered systems used for silicon microelectronics, but rather to develop different kinds of capabilities that might be complementary to those well-established approaches.

The group is focusing on two initial areas: plastic electronics and nanophotonics, both of which are well matched to unconventional patterning techniques, says Rogers.

His group s gold film research, for example, is aimed at creating plastic electronics. Chemical stability, according to Rogers, makes gold a good material for flexible electronic systems. Gold doesn't form an oxide in chemical reactions, so you can put an organic semiconductor on top of printed gold electrodes and form transistors with very good properties, he says.

But plastic semiconductors don t play well with the photoresists used in conventional chip making, so nTP provides a needed alternative. And because nTP can stamp patterns on an exceedingly small scale, the process can deliver size advantages to rival silicon transistors.

Smaller circuitry means higher switching speeds, lower power consumption, and higher current output, so nTP translates directly into better performance in flexible transistor applications. Rogers says his team has used nTP techniques to build simple inverter circuits a fundamental building block of digital systems that change a zero into a one or a one into a zero.

Nanophotonics

In exploring nanophotonics, the Rogers group has designed multi-layer, nanoscale lattice structures with features much smaller than the wavelength of light. The lattice can be tuned to alter the spectral properties of light that passes through. "This is very new stuff, notes Rogers. We're just now trying to measure the photonic properties."

Such nanophotonic lattices could be used to clean up optical signals, which often suffer refraction distortion (known as birefringence) as they propagate through high-speed communications networks. Rogers, who spent five years at Bell Labs before coming to UIUC in January, is exploring ways of aligning liquid crystals using nTP-printed nanochannels. Once perfected, the approach will deliver low-cost, sub-wavelength lattice structures suitable for high-speed polarization control and measurement.

The group has used nTP to build lattice features only 50 nanometers wide. That s roughly half the size of features found on microprocessors made with today s most sophisticated lithography tools.

No one's been able to build these things before, he says. We don't even know what the photonic properties are going to be, but we have a strong sense it's going to be interesting."

Other apps

Other potential applications abound for nTP. For example, the Rogers group has printed hybrid micro-nanochannel arrays (imagine rows of parallel microfluidic channels orthogonally linked by hundreds of

far-tinier nanochannels). These structures may help scientists understand how fluids flow at the nanoscale. They might also be used to mold wires for nanoscale electronics.

The nTP approach can also be used to print suspended beam resonators and other small structures for nanoelectromechanical systems, including sensors that can detect trace amounts of chemicals.

Rogers is optimistic about the prospects for nTP: "The printing approach is a good one for us to be exploring. This is a basic fabrication tool, so the kinds of applications are limited only by your imagination."

Commercialization

The nanomaterials market is starting to climb the growth curve
Small Times 8/28/2003 - Nanomaterials are really starting to get traction in several areas, and markets for nanomaterials are expected to grow to $20 billion by 2103 according to Consulting Resources Corporation. Currently, nanoparticle oxides are the most mature, and Chicago's Nanophase Technologies Corporation leads the way. Nanoclays are also advancing rapidly, led by Chicago's Nanocor.
http://www.smalltimes.com/document_display.cfm?document_id=6523

nPoint Advances Nanopositioning Flexibility With New 300-Series DSP Controller
Nano Investor News 8/27/2003 - nPoint, Inc, the global leader in ultra-precision motion and control nanopositioners for nanoscale research and manufacturing, today introduced the 300-Series DSP (digital signal processor) Controller. The new DSP-based controller is an integral component of nPoint's ultra-precision positioning products. The applications include critical dimension measurements on semiconductors and semiconductor masks, atomic force microscopy, and other scanning probe instruments.
http://www.nanoinvestornews.com/modules.php?name=News&file=article&sid=1774

AMD's purchase of Coatue could boost its memory, signal strategy
Small Times 8/27/2003 - AMD s purchase of Coatue and re-sale to its joint venture with Fujitsu, FASL, LLC is an indication that the semiconductor industry is starting to really look at investing in nanotechnology memory technologies. Expect to see more players beginning to make similar strategic investments to secure options to play in the future as nanotech approaches mature.
http://www.smalltimes.com/document_display.cfm?document_id=6566

Honey I shrunk the robots
NanoApex News 8/25/2003 - Micro-robots, dubbed nanotools, have been developed by California-based Innovation On Demand to be operated wirelessly by focused beams of energy. They will be able to control objects as small as 100 nanometers across. Predicted uses of the micro-robots would be for drug discovery, construction and control of medical devices such as valves and microsurgical instruments, and the manipulation of proteins and genetic components.
http://www.computing.co.uk/News/1143162#http://www.computing.co.uk/News/1143162#

2002 Tough, But MEMS Still a Solid Business **Opportunity Reports In-Stat/MDR**
Nano Investor News 8/22/2003 - Promoting its latest market report, In-Stat/MDR reports that year over year revenues grew just 4.4% from $3.8 billion in 2001 to $3.9 billion in 2002 even though unit shipments increased 47.6% for the MEMS industry.
http://www.nanoinvestornews.com/modules.php?name=News&file=article&sid=1757

When Flash becomes a memory
NanoApex News 8/22/2003 - A good overview of competing non-volatile RAM technologies. A

worthwhile read for someone wanting to understand the alternatives and where they fit.
http://www.electronicsnews.com.au/articles/c9/0c018ac9.asp#http://www.electronicsnews.com.au/article

Nanomaterial overcomes weather woes in bid to save scorched land
Small Times 8/21/2003 - Sequoia Pacific Research Company, LLC has developed a soil binder, a nanostructured matrix of organic, biodegradable concentrate called SoilSET. Once the concentrate has been mixed with water, an electrochemical reaction creates an organic binder at the nanoscale, which sticks to soil to retain water. It also reduces runoff and helps germinate seeds, allowing rapid reseeding of forests and other damaged lands.
http://www.smalltimes.com/document_display.cfm?document_id=6540

Kopin Licenses Patents from North Carolina State University
Nano Investor News 8/21/2003 - Kopin Corporation (NASDAQ: KOPN), the leading developer of nano-engineered semiconductor components including microdisplays, high-brightness light-emitting diodes (LEDs) and transistors for mobile applications, announced that it has exclusively licensed a patent on Domain Epitaxy and two patents on cubic Zinc-Magnesium-Oxide (ZnMgO) and Zinc-Cadmium-Oxide (ZnCdO) from North Carolina State University. These patents are important because they can be used to produce LEDs and lasers of any color across the visible spectrum, including the three primary colors needed for white LEDs.
http://www.nanoinvestornews.com/modules.php?name=News&file=article&sid=1755

Nanosys Signs Agreement with SAIC to Pursue Nanotechnology
Nano Investor News 8/21/2003 - Nanosys, Inc. announced that it has signed a Master Marketing and Business Development Agreement with SAIC to jointly pursue and identify opportunities that can deliver nanotechnology enabled solutions for civil, homeland security, and national defense applications under government contracts.
http://www.nanoinvestornews.com/modules.php?name=News&file=article&sid=1754

Obducat-Investor's darling
Nano Investor News 8/20/2003 - Profile on Obducat, a Malmo, Sweden based company focused on micro- and nanoimprint lithography, electron beam lithography and scanning electron microscopes. With $4 million in annual revenues, they are poised to be a mass-producer of nanotech tools.
http://www.nanoinvestornews.com/modules.php?name=News&file=article&sid=1751

Nano marketing
Nano Investor News 8/19/2003 - Applied NanoWorks, based in the Rensselaer Polytechnic Institute Incubator, makes nanoparticles by combining high-purity water, a powder material such as silicon and an etchant, which is a chemical that reduces the size of the particles. The company says it can make nanoparticles out of 64 materials, including cadmium sulfide, aluminum oxide and silicon. These nanoparticles could find their way in products as varied as cosmetics and hand lotions to provide greater UV protection, and rubber tires to make them more durable.
http://albany.bizjournals.com/albany/stories/2003/08/18/smallb1.html##

The New Diamond Age
Nano Investor News 8/19/2003 - Using different approaches, Genesis of Sarasota, Florida and Boston-based Apollo Diamond have developed technology to make gem-quality, multi-carat synthetic diamonds cheaply. After transforming the diamond industry, they plan to do the same with the semiconductor industry.
http://www.wired.com/wired/archive/11.09/diamond.html##

What's wrong with the grid? It's dumb; sensors might make it smarter
Small Times 8/19/2003 - Even as the energy industry struggles to understand why last week's blackout

occurred, experts are examining ways in which small tech could help prevent it from happening again. And they're finding at least one new way to make the grid run more efficiently: microsensors. Not only more efficiently, but "smarter." The MEMS-based systems can do that by circulating up-to-date information about what s going on within the power systems.
http://www.smalltimes.com/document_display.cfm?document_id=6522

Research

A Sharper Picture of Health
MIT Technology Review 9/1/2003 - Northwestern Professor Thomas J. Mead discusses powerful new imaging technologies pinpoint the molecular events involved in diseases, promising a safer alternative to biopsies.
http://www.mittechnologyreview.com/articles/hamilton0903.asp

Microscopic Business
Nano Investor News 8/27/2003 - Amphora Laboratory had developed a modulation interference microscope (MIM) that gives a 3D image of objects ranging from 5 to 200 nm in size and a vertical-line resolution of 0.1 nm. If Amphora can manage to promote its MIM, it could capture up to 40% of the global market for microanalysis instruments, currently estimated at $5.8 billion.
http://www.gateway2russia.com/st/art_131641.php##

UGA faculty of engineering researchers awarded $1 million NSF grant to develop nanoscale biosensors
NanoApex News 8/27/2003 - The National Science Foundation has awarded $1 million to a team of University of Georgia researchers to study and develop 3-D nanoscale structures to address problems in biosensing. The increasing demand and interest in developing implantable glucose sensors for treating diabetes has led to notable progress in this area and the team plans to refine key issues of long-term calibration and other aging effects on the sensors.
http://news.nanoapex.com/modules.php?name=News&file=article&sid=3753

Electronic nanotechnology will sustain Moore's Law
NanoApex News 8/22/2003 - Carnegie Mellon professor Seth Goldstein said that field programmable gate array (FPGA) devices which use electronic nanotechnology and molecular electronics will keep Moore's Law alive and well in the future. The new class of electronics devices which is called chemically assembled electronic nanotechnology (CAEN) will be low power, defect tolerant and provide massive component densities at low cost in the future.
http://news.nanoapex.com/modules.php?name=News&file=article&sid=3736

DNA computer unbeaten at tic tac toe
NanoApex News 8/22/2003 - A DNA computer called MAYA, invented by Milan Stojanovic, of Columbia University in New York, and Darko Stefanovic, of the University of New Mexico in Albuquerque, demonstrates the ability to embed logic into biological systems. Molecular automatons might one day find medical uses. Injected into the blood, they could recognize molecules on cancerous or healthy cells to deliver a drug accurately.
http://news.nanoapex.com/modules.php?name=News&file=article&sid=3737

Nanotubes boost ceramic performance
NanoApex News 8/21/2003 - Single-walled carbon nanotubes have been used to increase the electrical conductivity of alumina by 13 orders of magnitude. Guo-Dong Zhan and colleagues at the University of California at Davis have taken a sample of alumina, which is a ceramic insulator, and turned it into a fracture-resistant composite with a conductivity that is over 735% higher than the previous record for a nanotube-ceramic composite.
http://news.nanoapex.com/modules.php?name=News&file=article&sid=3732

Toxic protein could explain Alzheimer's and lead to breakthroughs
NanoApex News 8/20/2003 - Researchers at Northwestern University have identified a toxic protein they believe to be responsible for the memory loss found in patients with Alzheimer's disease. William Klein's team is now collaborating with the Institute for Nanotechnology to develop clinical diagnostics capable of detecting ADDLs in blood or cerebral spinal fluid.
http://news.nanoapex.com/modules.php?name=News&file=article&sid=3730

Nanobelts coil up for piezoelectricity
NanoApex News 8/20/2003 - Researchers from the Georgia Institute of Technology, US, have made single-crystal zinc oxide (ZnO) nanobelts that spontaneously rolled themselves up into helical structures. The nanohelixes had piezoelectric properties and could have applications in microsystems and the biomedical field.
http://news.nanoapex.com/modules.php?name=News&file=article&sid=3727

Purdue researchers expose 'Docking Bay' for viral attack
NanoApex News 8/20/2003 - Using advanced imaging techniques, an international team of biologists led by Michael Rossmann of Purdue, Vadim Mesyanzhinov in Moscow and Fumio Arisaka at the Tokyo Institute of Technology has analyzed the structure of part of the T4 virus, which commonly infects E. coli bacteria. The part they analyzed, called the baseplate, is a complex structure made of 16 types of proteins that allows T4 to attach itself to the surface of E. coli in order to inject its own deadly genetic material. Their work has produced the clearest picture ever obtained of the baseplate, which plays a critical role in the initial stages of viral infection. "The baseplate of this virus is essentially a complex molecular machine," Rossmann said. "We have now obtained a clear picture of its structure, which has allowed us to suggest how it works. Building nanomachines will likely be easier if we can borrow some mechanisms already proven by nature."
http://news.nanoapex.com/modules.php?name=News&file=article&sid=3729

Sandia researchers create nanocrystals nature's way
Small Times 8/19/2003 - Sandia researchers are developing complex nanomaterials that look strikingly similar to the microstructures of diatoms and seashells. The materials may have potential for a wide range of applications.
http://www.smalltimes.com/document_display.cfm?document_id=6528

Policy

Welcome to Nano Reality TV, where the show is mistaken for truth
Small Times 8/29/2003 - A well written piece by Howard Lovy that exposes the misinformation being disseminated by anti-globalization groups who are couching their agenda in environmental activism.
http://www.smalltimes.com/document_display.cfm?document_id=6571

NSF awards grants to study nano in society
Small Times 8/26/2003 - The National Science Foundation (NSF) has announced two new grants, well over $1 million apiece, that greatly expand its ongoing commitment to study the societal implications of nanotechnology: the emerging discipline that seeks to control and manipulate matter on a molecular scale. The grants will be by far the largest awards the foundation has devoted to societal implications exclusively.
http://www.smalltimes.com/document_display.cfm?document_id=6564

Molecular Manufacturing: Start Planning
NanoApex News 8/25/2003 - Chris Phoenix, the Director of Research for the Center for Responsible Nanotechnology, provides a coherent view of the future of how the combination chemistry and

nanotechnology will create nanofactories in the next decade, and describes both the value and policy implications of the technology.
http://news.nanoapex.com/modules.php?name=News&file=article&sid=3745

Darpa Head Skeptical About Quantum Computing
NanoApex News 8/22/2003 - Robert Leheny, director of the Microsystems Technology Office at the Defense Advanced Research Projects Agency (Darpa, Arlington, Va.), offered his office's view of the future promises-and possible dead-ends-in microelectronics at a keynote speech at the Hot Chips Conference held August 19 in Palo Alto, California. Along with other concerns, quantum computers were described as non-scalable due to the inherent analog nature of the system.
http://news.nanoapex.com/modules.php?name=News&file=article&sid=3740

Events

Nanotech to take a flying leap off the ivory tower for Chicago event
Small Times 8/28/2003 - Organizers of a new nano conference promise to make this one stand out from the others by emphasizing business and products, rather than research and theory. Sure to be the signature event of 2003&
http://www.smalltimes.com/document_display.cfm?document_id=6569

CDMA Nanotech Strategic Partner Program
AtomWorks is pleased to partner with the Chicago Chapter of the Commercial Development and Marketing Association (CDMA) in developing a free consultation service for nanotechnology companies that are interested growing their business. The CDMA has assembled a panel of market experts that will counsel participating nanotechnology start-ups in how to develop effective marketing techniques and educate them about the process of selling disruptive technology to Fortune 500 companies. Participating companies will have the opportunity to deliver their marketing presentations to our expert panel for review and coaching. In addition, participating companies will have the opportunity to present their revised presentation at the CDMA national meeting, which brings together business leaders in the technology sector from around the country.

Initial presentations will be held on Wednesday, November 5, 2003 at Brinks Hofer Gilson & Lione, NBC Tower, 455 North Cityfront Plaza, Suite 3600, Chicago, IL beginning at 6:00 p.m. The non-confidential presentation should be planned to be presented in 15 minutes with a very strong emphasis on the envisioned product, value chain, marketing position, targeted first sales, and sales/development approach.

In order for your company to be considered for this program, you must complete the questionnaire at http://www.surveymonkey.com/s.asp?u=23246264221 by September 18, 2003. In the future, we may be able to offer this program to additional companies, but we are currently only able to extend this opportunity to two nanotechnology companies in the Midwest that sell nanotechnology products in the area of diagnostics or sensors. If your company is selected you will be notified by October 1, 2003.

For more information about the CDMA, please visit their website at www.cdmaonline.org. If you have any general questions regarding the Selling to Strategic Partners Program, please direct them to Bryan Sugar at bsugar@brinkshofer.com. If you have specific questions about the coaching process, please direct them to Ada C. Nielsen at NielsenC@bp.com.