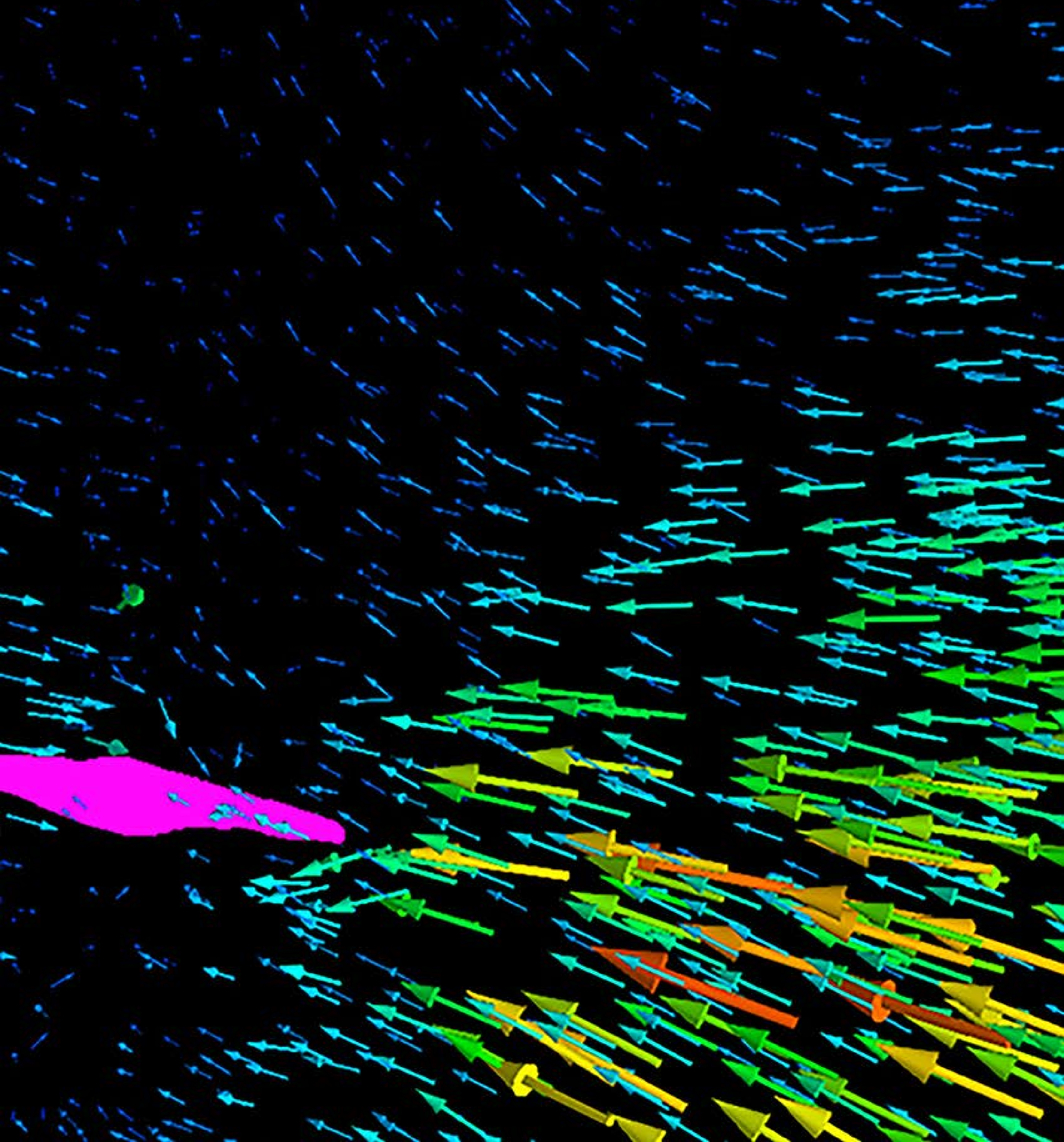
NanoMeter

The Newsletter of the Cornell NanoScale Facility
Spring 2017 • Volume 26 • Issue 1



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CNF TCN

Technology & Characterization

JUNE 6 - 9, 2017

CORNELL UNIVERSITY, ITHACA, NY

This intensive 3.5 day short course offered by the Cornell NanoScale Science & Technology Facility, combines lectures and laboratory demonstrations designed to impart a broad understanding of the science and technology required to undertake research in nanoscience. TCN is an ideal way for faculty, graduate students, post docs and staff members to rapidly come up to speed in many of the technologies that users of the CNF need to employ. Members of the high tech business community will also find it an effective way to learn best practices for success in a nanofab environment. Attendance is open to the general scientific community, but class size is limited.

REGISTER TODAY!

http://www.cnf.cornell.edu/cnf_tcn_june_2017.html

Reminder to Submit to CNF User Wiki

Dear CNF Community: Please remember to share your process and recipe updates on the CNF User Wiki.

wiki.cnfusers.cornell.edu

Photography Credits

The cover image for this issue is from Mingming Wu's article that starts on page 18. The background image is a throw-back to the 2007 issues—an Intel wafer scanned in long ago! Photographs through-out this issue are [1] attributed to the persons noted in the article, [2] taken by Don Tennant, or [3] Photographer Unknown.

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CNF Cornell NanoScale Science and Technology Facility

National Nanotechnology Coordinated Infrastructure

Cornell University

NYSTAR

NSF

Welcome to the 2017 Spring Edition of the CNF NanoMeter

In this Spring 2017 edition of the NanoMeter, we are glad to provide you with the latest news from the Cornell NanoScale Facility. Inside you will find research highlights, information about our annual meeting, and some exciting new results from our staff.

Fall 2017 CNF Annual Users Meeting

This year is a special year — we are celebrating our 40th anniversary! To recognize this milestone and to plan for the future, we are holding a special symposium this fall on Thursday, September 14, in place of our usual Annual Users Meeting.

We are planning a day of invited talks presented by leaders in nanoscience covering the topics of the internet of things, 2D materials, nanoscale biology, and biomedicine and nanophotonics. A second day will include invitation only breakout sessions to discuss CNF needs and capabilities for these and related topics. As we go forward, we want CNF to remain a forefront facility and such activities will help us as we plan for the future.

If you are interested in attending the symposium, it is open to the public — please join us! If your company is interested in sponsoring this special event, please contact Don Tennant directly (tennant@cnf.cornell.edu).

More information can be found (as it develops) at our webpage:

http://www.cnf.cornell.edu/cnf_2017am.html

New Equipment and Processes

In this issue we include four articles by staff about new processes and lab upgrades that we have been working on. You can find out about new plasma etch processes that have been developed in our Oxford Instruments Cobra ICP Etcher in a report from Vince Genova; new materials and processes that have greatly improved our nanoimprint pattern transfer recipes — also from Vince; a new gizmo built by Ed Camacho for edge bead removal of photoresist; and some new PECVD TEOS thin film characterization data from our staff material scientist, Xinwei Wu.

Network Update

The National Nanotechnology Coordinated Infrastructure (NNCI) has now been going for almost a year. We have had a chance to meet members of the different sites and the network is looking

Through-out this issue we will feature photographs from the forty years of Cornell NanoScale Facility history! To the left are a few of the first tools used in the Phillips Hall laboratory, circa 1978. Photographer unknown.

for ways we can all better work together. There is a new NNCI website (nnci.net) that describes the network and tools at each location. Experts and capabilities of each site in the network are also listed. NNCI has established working groups of staff experts to spread experience around the network.

We would be interested in learning from you how easy it is to use the NNCI website and if you have any thoughts about capabilities you would like to see at CNF or in the network.

NNCI is organized by region and our east coast partners include:

- Mid-Atlantic Nanotechnology Hub for Research, Education and Innovation, University of Pennsylvania with partner Community College of Philadelphia
- Southeastern Nanotechnology Infrastructure Corridor, Georgia Institute of Technology with partners North Carolina A&T State University and University of North Carolina-Greensboro
- The Virginia Tech National Center for Earth and Environmental Nanotechnology Infrastructure, Virginia Polytechnic Institute and State University
- North Carolina Research Triangle Nanotechnology Network, North Carolina State University with partners Duke University and University of North Carolina-Chapel Hill
- The Center for Nanoscale Systems at Harvard University, Harvard University

As we learn more about the synergistic capabilities of our partners we are looking forward to further ways to work with them.

University Photography

Chris Ober and Don Tennant

An artist's rendering of the Lester B. Knight building plans, circa 1980. Artist unknown.

CNF 40th Anniversary Symposium!

•• 1997-2017 ••

Postcard of Phillips Hall, circa 1950s. Photographer unknown.

To celebrate our 40th anniversary, the 2017 Cornell NanoScale Facility Symposium will include special events around the main day of the meeting, Thursday, September 14, 2017.

Guest speakers will look back at our forty successful years in nanofabrication — and look forward to new vistas in nanotechnology.

Keep an eye on this site — http://www.cnf.cornell.edu/cnf_2017am.html — for announcements and schedules regarding our 40th anniversary celebration!

2016 CNF Staff. University Photography.

Used with permission from DLJ Photography.

NSF Awards Xallent with a Phase II SBIR Grant

October 5, 2016

Ithaca, NY – Xallent, LLC., announced today (Oct.5) that the National Science Foundation (NSF) has awarded the company a Phase II Small Business Innovation Research (SBIR) grant of $750K to support the commercialization of their breakthrough nanomachine probing technology. The two-year grant will fund product development and recruitment of top talent.

Conventional characterization and test methods are increasingly ineffective when applied to structures less than 100 nm, causing challenges across R&D, process control, and failure analysis. Given slow, complex detection processes, identification of subtle defects typically takes weeks or months following fabrication. This translates to significant waste as systemic issues can persist untreated across multiple batches. Xallent's nanomachine probing technology directly addresses these challenges with simple, cost effective, and high speed testing solutions.

"This Phase II grant reaffirms the powerful potential impact of our nanomachine probing technology to address critical testing challenges in the thin film and semiconductor industries. The simple micro- to nanoscale testing paradigm enabled by our technologies will have far reaching commercial and societal impact, magnified by the powerful trends driving science and engineering at the nanoscale across devices, materials, and biological systems. Our technology enables researchers, scientists, and engineers to dramatically cut the time, cost, and complexity of research, development, and production of advanced thin films and semiconductor devices." said Dr. Kwame Amponsah, Founder and CEO of Xallent.

Mission Statement

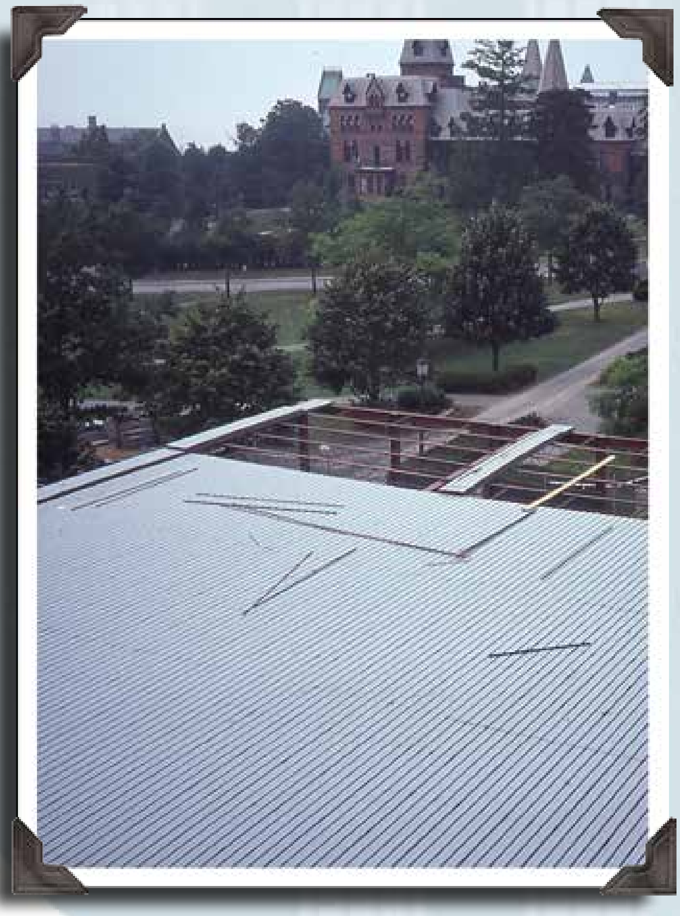
Xallent designs, develops, manufactures, and markets advanced nanoprobing solutions for imaging, electrical measurement, and testing of thin film materials and semiconductor devices. Our products enable on-wafer measurements and failure analysis of integrated circuits. Our products are also used for electrical, structural, and mechanical characterization of thin film materials. Product design, manufacture, and assembly are conducted in Ithaca, New York. For more information, please visit www.xallent.com.

Contact:

Kwame Amponsah, Ph.D.
Founder and CEO
kwame.amponsah@xallent.com
607-262-0515

Our mailing address:

95 Brown Road
M/S 1035
Ithaca, NY 14850



Above: The Knight Lab construction, circa 1980. Photographer unknown.

Researchers Turn Ordinary Fibers Into Water, Air Purifiers

By Darren Chow
The Cornell Daily Sun
11/29/16, 9:59 AM

> "I think the main advantage of our polymer is that we can capture the pollutants extremely fast."
>
> PROF. JUAN HINESTROZA

For centuries, rivers have sustained human civilization. From the Nile to the Indus, these blue-green and brown waters have been invaluable sources of irrigation. Unfortunately, they are equally convenient for waste disposal. Over time, cocktails of industrial effluents have caused these rivers to acquire much darker hues. Fortunately, Prof. Juan Hinestroza, fiber science, has created a pollutant-absorbing fiber that could help restore rivers to their former glory.

"I often know what color is in fashion in the U.S. by looking at a river because some of the chemicals used in manufacturing are thrown into lakes and rivers," Hinestroza said. "It's so sad because people have to drink that water. As a result, what we wanted to do is create a material that could capture pollutants from air and water."

Hinestroza developed the polymer using a process known as cyclodextrin polymerization to coat the surface of a cotton fabric. Polymerization is the process of reacting molecules together in a chemical reaction to form polymers, large molecules of repeated subunits. The resultant material is capable of filtering a variety of contaminants, including Styrene and Bisphenol A. BPA is known to cause a variety of negative health effects, including breast cancer, early puberty, heart disease, and infertility.

"Cyclodextrin is a very beautiful molecule. On the outside it's hydrophobic and on the inside it's hydrophilic," Hinestroza explained. "It works because of the chemical affinity of the molecule – it is able to capture the pollutants inside and reuse them."

He uses the analogy of a cup to explain how the polymer captures these pollutants. "The polymer is like a little cup. When we put the cups together the contaminant gets captured. We can release the pollutants by changing the pressure or heating it up slowly," Hinestroza said. "That's an advantage because we can reuse the polymer."

Hinestroza's polymer has numerous other advantages over those that already exist. For example, companies can easily incorporate it into their manufacturing processes without needing to procure new machines or make special changes to manufacturing conditions.

"I think the main advantage of our polymer is that we can capture the pollutants extremely fast," Hinestroza said. "We decided to benchmark our polymer with commercial solvents and we ended up being several orders of magnitude faster in capturing large amounts of pollutants without saturation."

The process is not exclusive to cotton. Cotton was only chosen as the testing material due to its common use and low level of testing difficulty.

"We can coat polyester, we can coat nylon, we can coat any other textile fiber," Hinestroza said. "Once you have it as a fiber, you can produce a t-shirt, a filter, a carpet, a curtain, anything. All these different objects can clean the air." Hinestroza said he hopes that such polymers will eventually be used in other industries as well.

"We want to see it become much bigger than the textile industry. It will be nice to have clothing that can clean water and air, but we also see these filtering juices, packaging food and as architectural textiles," Hinestroza said.

In fact, one of Hinestroza's main goals is to develop a 'super-suit' capable of repelling stains, changing colors and healing minor wounds.

"We work on interactive textiles, so cleaning the air and water is only one aspect. We are also working on clothing that changes colors without pigments. For example, when there is an allergen close by, the clothing will change colors to alert you. If someone spills wine on the clothing, it should be able to repel the stain and scent."

FuzeHub Announces Grant Awards from the Five-Million-Dollar Fund to Support Innovation and Manufacturing Throughout New York State

Over $469,000 awarded to seven projects, and adding 46 jobs across New York State

Albany, NY; March 1, 2017 — FuzeHub, a not-for-profit organization responsible for assisting small to medium-sized manufacturing companies (SMEs) in New York State by matching them with technical and business resources, recently launched the Jeff Lawrence Manufacturing Innovation Fund. Lawrence, who passed away in 2015, was a top executive at the Center for Economic Growth, the Manufacturing Extension Partnership (MEP) center for the Capital Region, and a champion for New York manufacturing and entrepreneurial communities.

The Manufacturing Innovation Fund, consisting of $1 million annually for five years, supports a set of activities designed to spur technology development and commercialization across New York State. FuzeHub is administering this fund as part of its role as the Empire State Development (ESD)-designated statewide MEP center.

As part of the fund, FuzeHub offers Manufac--turing Innovation Grants (MIGs). The grants are available to not-for-profit organizations, including higher education institutions, in New York State proposing innovative projects to be undertaken with small and mid-sized manufacturers or early stage companies.

Projects can include prototype development, proof-of-concept manufacturing, certain equipment purchases, manufacturing scale-up, market identification, and other projects to advance manufacturing capabilities. The fund will also be used to launch a commercialization competition this fall, with plans to formally announce the details in late spring.

The second round of grant awardees are projected to incrementally add 46 new jobs to both existing and startup companies across New York State in the next two years.

"One of the goals of the fund, and the MIGs, is to spur economic development in the manufacturing sector, and we're seeing that even these small investments in manufacturing projects are allowing companies to add jobs, strengthening their teams and contribute to their growth," FuzeHub Executive Director Elena Garuc noted.

"These projects are a great example of how New York's innovation assets are supporting industry and contributing to economic growth in New York," she added.

FuzeHub is pleased to announce the second set of grantees:

Center for Economic Growth - $75,000

- The Center for Economic Growth (CEG) is working with ThermoAura Inc. to help them with the integration of new equipment into their manufacturing process to enable the high-volume manufacture of advanced nanocrystalline thermoelectric alloys. (Capital Region)

Clarkson University - $75,000

- Clarkson University is creating a new shared laboratory for both academic and industry collaboration in which both will have access to laboratory tools and equipment. (North Country)

Cornell Center for Materials Research - $58,926

- Cornell Center for Materials Research (CCMR) and Professor Yong Joo of Cornell University's School of Chemical and Biomolecular Engineering are working with IdealChain, a spinoff of Buckingham Manufacturing, who manufactures safety products (harnesses, rescue systems, etc.), to develop and build a bench-scale multi-nozzle Air-Controlled (AC) electrospray system for encapsulation of dyes, to use as stress indicators in safety products. (Southern Tier)

Cornell Nanoscale Facility - $75,000

- The Cornell NanoScale Science and Technology Facility (CNF) at Cornell University has partnered with Xallent LLC to develop a next generation diagnostic tool to more rapidly and economically test and characterize semiconductor devices and thin film materials during manufacturing. This tool is built on Xallent's innovative nanoscale imaging and probing technology. The ability to rapidly probe and measure electrical components at the nanoscale for diagnostics and failure analysis non-destructively is expected to tap a broad range of industry applications. The Manufacturing Innovation Grant will be used to adapt Xallent's nanomachine platforms to analytical instruments at the Cornell NanoScale Facility for validation, user interface focus, and reliability studies to ready the company for product launch and scale up. Additionally, this project will help Xallent add eight new jobs by the end of 2019. (Southern Tier)

Cornell University - $74,980

- Cornell University researchers and VitaScan have developed the VitaScan diagnostics platform: a low cost and portable instrument that can determine micronutrient deficiencies including vitamin D and iron from a finger stick of blood. to create 10 new jobs in the next two years. (Southern Tier)

Rochester Institute of Technology - $75,000

- Rochester Institute of Technology (RIT) is working with OptiPro Systems on a project to develop an innovative ultrafast-laser-based polishing system and process for optical manufacturing to eliminate polishing waste, long lead-time, and high-cost factors. (Finger Lakes)

Rochester Institute of Technology - $36,000

- RIT's Additive Manufacturing and Multifunctional Printing (AMPrint) Center is working with Sensor Films on a project to define the operating conditions for high throughput additive manufacturing equipment capable of rapidly printing electrically conductive patterns on plastic substrates. (Finger Lakes)

About FuzeHub

FuzeHub is a not-for-profit organization that connects New York's small and mid-sized manufacturing companies to the resources, programs and expertise they need for technology commercialization, innovation, and business growth. Through our custom assessment, matching, and referral platform, we help companies navigate New York's robust network of industry experts at Manufacturing Extension Partners centers, universities, economic development organizations, and other providers. FuzeHub is the statewide New York Manufacturing Extension Partnership Program (MEP) center, supported by Empire State Development's Division of Science, Technology & Innovation. For more information on FuzeHub, visit www.fuzehub.com.

About Empire State Development's Division of Science, Technology and Innovation (NYSTAR)

Empire State Development's Division of Science, Technology and Innovation (NYSTAR) mission is to advance technology innovation and commercialization in New York State. NYSTAR's programs are designed to enable new and existing businesses to become more competitive through the use of innovative technologies, and emphasize the importance of working with industry to leverage the state's technology strengths. Through funded programs that support world-class technology research at colleges and universities, NYSTAR works to promote a robust network of industry-university partnerships throughout the state. It administers the New York Manufacturing Extension Partnership, which provides direct technology assistance to small and medium size manufacturers.

About Jeff Lawrence

During his more than 20 years at the Center for Economic Growth, the Manufacturing Extension Partnership (MEP) affiliate in the Capital Region where he served as executive VP, and MEP Center Director, Jeff Lawrence directed programs of direct assistance to manufacturers and technology companies to increase their competitiveness. He is remembered for being an invaluable and generous mentor to many in the area's business community and a tireless advocate for manufacturing innovation throughout New York.

For more information about the Jeff Lawrence Manufacturing Innovation Fund, visit http://fuzehub.com/manufacturing-innovation-fund/ or contact FuzeHub Industry Engagement Manager Amber Mooney at amber@fuzehub.com.

Below: The Knight Lab construction. Photographer unknown.

Paul McEuen on Nanoscience and Bridging Disciplines

By Joe Wilensky
Cornell Chronicle
Nov. 2, 2016

Paul McEuen, the John A. Newman Professor of Physical Science and director of the Kavli Institute at Cornell for Nanoscale Science, is heading Provost Michael Kotlikoff's new faculty hiring initiative task force on nanoscale science and microsystems engineering (with co-chair Prof. David Muller). He spoke to us about pushing nanoscience at Cornell to the next level, the challenge of recruiting midcareer faculty who bridge disciplines, "radical collaboration," and the importance of asking, "What if?"

How did this nanoscience task force come to be?

It started with a vision, and a crisis.

First, the vision: one of a future where we make tiny machines as easily as we now make miniaturized electronics. The last 50 years belonged to the electronics revolution, where research on small electronic devices brought us the information technologies that are so important today. The next 50 years will bring a similar revolution in what you might call miniaturized robotics. And these small machines will be used for everything from medicine to environmental monitoring, from injectable surgical machines to fight cancer to environmental sensors small enough to fit inside a raindrop.

Now the crisis: Cornell has a long history as a world leader in nanoscience — arguably the world leader. But now other leading universities are trying to catch up, establishing programs and facilities with a nano focus. One way they do that is to hire faculty away from successful programs. That is happening to Cornell — we had some high-profile losses in nanoscience in the last couple of years.

These losses reminded us that we always need to be upping our game, to make an aggressive push to keep Cornell at the forefront of nanoscience. We decided that to take nano to the next level, we need to move beyond individual nanoscale objects and head toward nanosystems — assemblies of elements that perform a specific function. To make the vision of ubiquitous and powerful small machines a reality.

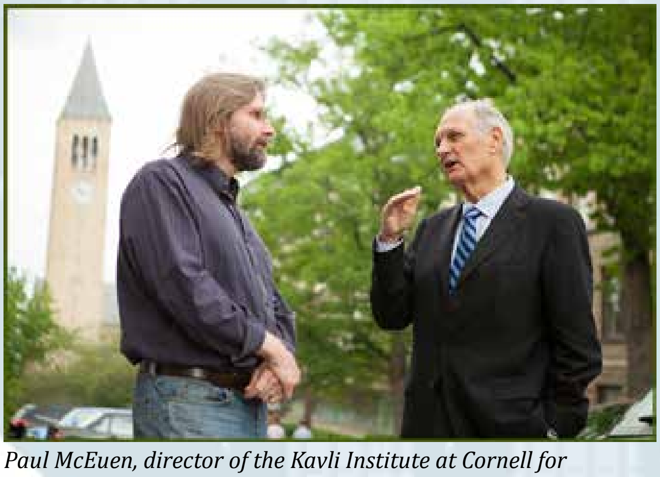
We interpret the term "nanomachines" very broadly — it could be biological, electronic, you name it … anything that's small. This initiative is an opportunity to do targeted hiring in next-gen nano that integrates chemistry, engineering, materials science and physics. Our goal is to hire early to midcareer faculty: young, recently tenured senior faculty who are at the top of their game, who have a strong sense of where they're going and want to team up to create this future. Such people are typically accomplished in multiple areas and would have a joint appointment between two departments, or at the very least could have a strong involvement in multiple departments or colleges. This integration will benefit the entire campus, not just an individual department.

We have a batch of outstanding candidates coming through now, and we hope to make a series of offers over the next few months and have a fantastic cadre of hires going into the next academic year.

What are some recent notable outcomes from Cornell nanoscale science research?

There are dozens of recent high-profile papers in nanoscience from Cornell. David Muller, my co-leader on this initiative, made it into the Guinness Book of World Records for creating the thinnest pane of glass, barely 3 atoms thick. Dan Ralph and Bob Buhrman have pioneered a new kind of magnetic memory that is finding its way into applications. Jan Lammerding, another member of our committee, found that cancer cells can damage their nucleus when squeezing through tiny microfabricated passageways. A number of us have gotten interested in creating the world's smallest foldable structures. It sounds fanciful, but origami and kirigami (a variation of origami) can be very powerful manufacturing technologies. It's a way of taking a two-dimensional sheet and folding it into the third dimension to create structures. At the moment, we're driven by curiosity – can we make these things? – but the applications will follow.

In environmental monitoring, if we could make one of these structures, put a bunch of electronic circuitry on it, have it fold up into a tight little package, go inside a



Paul McEuen, director of the Kavli Institute at Cornell for Nanoscale Science, chats with actor, director and writer Alan Alda on campus in 2013. Cornell Marketing Group file photo.

raindrop, fly somewhere, land, dry out and then start recording, that would be really fantastic. Can we make a "Fitbit for cells"? By that I mean electronic devices that are soft and compliant enough to go up to a cell and record information from it, without killing it?

Cornell excels at creating teams and facilities to take on these kind of big questions in nano. In 2017, for example, the Cornell NanoScale Science and Technology Facility will celebrate its 40th anniversary — we were nano before nano was cool. Cornell scientists have received funding for three new major centers in the last six months alone: the NSF-funded PARADIM, whose mission is to create new complex materials with atomic precision; the NCI-funded Center for the Physics of Cancer Metabolism, to understand and defeat cancer; and the NSF-funded Center for Bright Beams, to create new tools for imaging at the nanoscale. These interdisciplinary centers, totaling over $50 million in federal funding, show that Cornell is the right place for the provost's theme of "radical collaboration."

What will it take for this faculty hiring initiative, and the others the provost has rolled out, to be successful?

In senior hiring, you have to be willing to fail. You must make a lot of offers to get a few acceptances — these are the best people in the world, and they've got lots of options, so most offers are going to be turned down. The provost and the university must be willing to, as they say in Silicon Valley, "fail often."

The funding provided by the provost — as well as overall leadership, guidance, cajoling, etc. — will help make this kind of aggressive recruiting possible. And this is essential. To attract the kind of world-leading collaborative, interdisciplinary faculty we are looking for, ones who will benefit not just their home departments, but the larger Cornell community, we must show universitywide vision and commitment. The best faculty want to be a part of something big. So success means being proactive, risk-taking and bold. And the provost is leading the way.

Provost Kotlikoff has lauded you as a creative thinker who has excelled in your field and in training outstanding scientists. Can you describe your multidisciplinary approach?

You have to be willing to adapt and change and be comfortable in an environment where you don't quite know all that's going on — but you know you can make something exciting happen. Since I came to Cornell in 2001 (a midcareer hire!), our group has made the world's thinnest drum out of a single-atom-thick graphene sheet; we've made the world's smallest guitar out of a single carbon nanotube; we've started to use 1-atom-thick sheets to do kirigami with graphene sheets. We're very interested in taking these materials places they haven't been.

We try to be both focused and broad. First, you need something that is your specialty — something that defines you. If you go to my website, it says, "Anything, as long as it's small." That gives my group its focus; nano. But we'll go anywhere with it — electronics, mechanical devices, sensors; we'll study basic physics, or we'll make devices. We're driven primarily by a scientific and fundamental curiosity about how to play in this nanoscale world and not by a particular application or narrow notion about what these systems are good for. You can miss opportunities if you focus too soon. That said, we firmly believe that the work we do will be the bedrock of useful technologies in the future.

The students get trained very broadly. The research combines bits of chemistry, physics, materials science, engineering, you name it. And they have to chart their own path through this complex landscape, collaborating with chemists, materials scientists, biologists — the entire science and technology spectrum. And I'm very proud that my grad students and postdocs have done very well — over 20 are now professors at elite universities in departments ranging from chemistry to physics to mechanical engineering. One is even a patent law professor at Stanford. I think a part of their success is because, even as students or postdocs, they were trying to define their own objectives rather than me defining them. That freedom allowed them, when they became faculty, to choose great problems themselves.

You also are a novelist. Is a broad background and approach becoming a requirement today for any successful researcher?

Science is a great big puzzle. Over the past century, we were in an era of reductionist science. Everybody found their own little piece of the puzzle, and they learned more and more about it until they knew everything about the shape and form of their little piece. But the job of the future is to assemble those pieces into more and larger, more complex structures — of knowledge, of machines, of systems. It's a totally different game.

How do you put those pieces together in an interesting way? How do you understand something as "simple" as a bacterium? Or as complex as a human brain? The science of the future is one part biology, one part chemistry, one part soft-matter physics, one part information technology and one part ecology. It's a big and interesting challenge, and an organizational challenge, as well. We need to rethink how we organize the scientific enterprise. Cornell, as a research university, faces this challenge: How do we remain flexible, adaptive and relevant in a time when the boundaries of science/technology — and its role in the world — are changing so rapidly?

So being a writer is a great help. You have to create your own story. You have to say, "What if …?" and then see the question through.

Undergrad Researchers Make Pitches at CURBx

*By Amanda Bosworth**
Cornell Chronicle
Nov. 22, 2016

At CURBx – Cornell's version of TEDx Talks – seven undergraduate students each explained their humanities and STEM research in a five-minute presentation.

With research topics ranging from eating habits to the possibility of developing "invisibility cloaking" materials, the second annual CURBx Talk was held Nov. 21 in McGraw Hall. The event was organized by Alisha Nanji '19, an executive member of the Cornell Undergraduate Research Board, and emceed by co-president Ronald Forster '17. "I wanted to give students an opportunity to present their research in something other than the typical paper format. In addition, when people think about research, many immediately think of sciences such as biology and chemistry," said Nanji. "CURBx allowed students who are not involved in these types of sciences to also showcase their research, and it demonstrated how research can also be conducted in the humanities and social sciences."

The People's Choice Award for the best presentation went to Daniel Rosenfeld '18 for "Vegetarian Identity: The Psychology of Being a Vegetarian." He explained that vegetarianism is not just meat avoidance, but rather "an individual's thoughts, feelings and behaviors regarding being vegetarian." Our food choices, he said, distinguish us from friends and family and impact how they see us, how we see them and our self-perception. Vegetarianism is a social construct, he added, with many consequences for one's identity.

Athith Krishna '17, pictured at right, is researching the possibility of using hyperbolic materials to achieve the illusion of invisibility. Invisibility, he explained, is a matter of bending wavelengths. The only natural material that might act as a visual cloak is cubic boron nitride, and Krishna is partnering with the Cornell NanoScale Facility and the Cornell Center for Materials Research to explore its uses.

Elena Gupta '19, explained three studies she conducted on the benefits of weighing oneself. Gupta showed that study subjects ate less of a chocolate snack when they were first asked to weigh themselves. She proposed self-weighing as one way to combat obesity, because it stimulates individuals to eat less. Together, Madison Ulczak '17 and Suzy Park '18 explained their studies of juror reasoning. They found that, after listening to a trial recording, mock jurors made highly emotional decisions regarding defendant guilt or innocence. However, when deliberating with other jurors, emotions gave way to facts and details. Talia Bailes '20 conducted research last summer at a children's hospital in Cincinnati, Ohio. She assisted a physician/children's book author in testing the validity of a new screening tool for early childhood "emergent literacy" skills. By age 3, she said, children should have pre-reading skills — like how to hold a book and turn the pages. Orvill Delatorre '19 presented his work with civil engineering's Richardson Lab to test the purity of drinking water using a hollow-fiber filter and pump. The purpose of the system is to bring clean water to remote locations that currently lack needed infrastructure. Gabriella Lifsec '19 described her contribution to the ILR School's Worker Institute website. It was created as a complement to Professor Lowell Turner's 2014 book, "Mobilizing Against Inequality." Most recently, Lifsec has been collecting data on the Cornell student walkout to protest the election of Donald Trump and Ithaca's subsequent declaration as a sanctuary city for undocumented immigrants.

** Amanda Bosworth, a Cornell doctoral student in history, is a writer intern for the Cornell Chronicle.*

Photograph provided.

Engineers Create Room-Temperature Multiferroic Material

By Tom Fleischman
Cornell Chronicle
Sept. 22, 2016

Multiferroics — materials that exhibit both magnetic and electric order — are of interest for next-generation computing but difficult to create because the conditions conducive to each of those states are usually mutually exclusive. And in most multiferroics found to date, their respective properties emerge only at extremely low temperatures.

Two years ago, researchers in the labs of Darrell Schlom, the Herbert Fisk Johnson Professor of Industrial Chemistry in the Department of Materials Science and Engineering, and Dan Ralph, the F.R. Newman Professor in the College of Arts and Sciences, in collaboration with professor Ramamoorthy Ramesh at UC Berkeley, published a paper announcing a breakthrough in multiferroics involving the only known material in which magnetism can be controlled by applying an electric field at room temperature: the multiferroic bismuth ferrite.

Schlom's group has partnered with David Muller and Craig Fennie, professors of applied and engineering physics, to take that research a step further: The researchers have combined two non-multiferroic materials, using the best attributes of both to create a new room-temperature multiferroic.

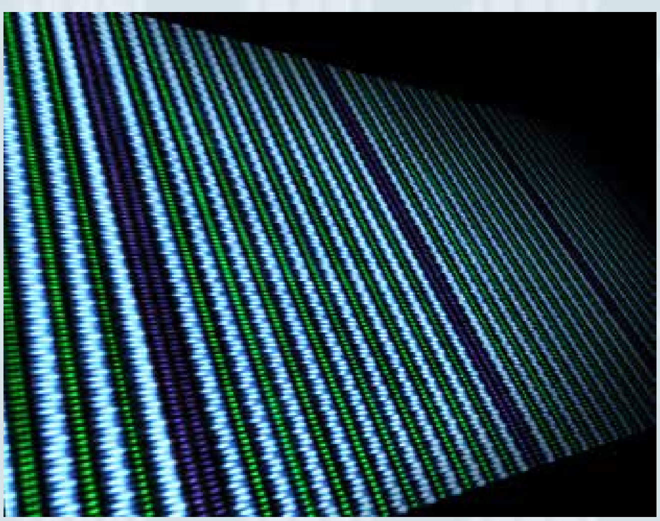


Figure 1: The magnetoelectric multiferroic created by a group led by Darrell Schlom, the Herbert Fisk Johnson Professor of Industrial Chemistry. The double strand of purple represents the extra layer of iron oxide, which makes the material a multiferroic at near room temperature. Image provided.

Their paper, "Atomically engineered ferroic layers yield a room-temperature magnetoelectric multiferroic," was published — along with a companion News & Views piece — Sept. 22 in *Nature*. The lead authors are Julia Mundy, Ph.D. '14, a former doctoral student working jointly with Muller and Schlom who's now a postdoctoral researcher at the University of California, Berkeley; Charles Brooks, Ph.D., a visiting scientist in the Schlom group; and Megan Holtz, a doctoral student in the Muller group.

The group engineered thin films of hexagonal lutetium iron oxide ($LuFeO_3$), a material known to be a robust ferroelectric, but not strongly magnetic. The $LuFeO_3$ consists of alternating single monolayers of lutetium oxide and iron oxide, and differs from a strong ferrimagnetic oxide ($LuFe_2O_4$), which consists of alternating monolayers of lutetium oxide with double monolayers of iron oxide.

The researchers found, however, that they could combine these two materials at the atomic-scale to create a new compound that was not only multiferroic but had better properties that either of the individual constituents. In particular, they found they need to add just one extra monolayer of iron oxide to every 10 atomic repeats of the $LuFeO_3$ to dramatically change the properties of the system.

That precision engineering was done via molecular-beam epitaxy (MBE), a specialty of the Schlom lab. A technique Schlom likens to "atomic spray painting," MBE let the researchers design and assemble the two different materials in layers, a single atom at a time.

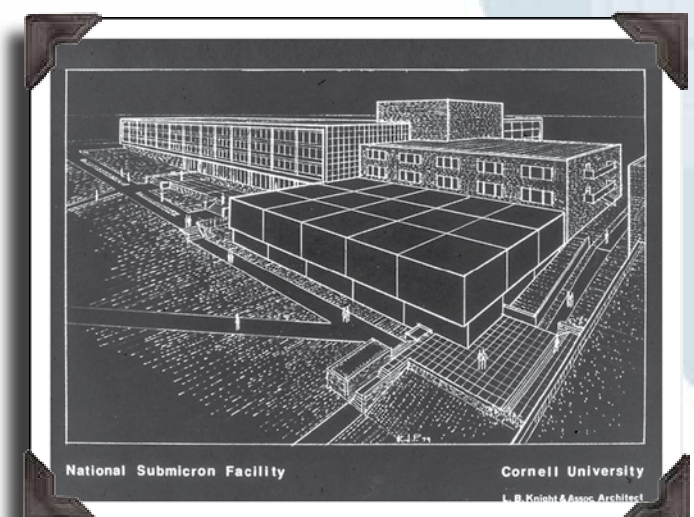
The combination of the two materials produced a strongly ferrimagnetic layer near room temperature. They then tested the new material at the Lawrence Berkeley National Laboratory (LBNL) Advanced Light Source in collaboration with co-author Ramesh to show that the ferrimagnetic atoms followed the alignment of their ferroelectric neighbors when switched by an electric field.

Continued on page 17

"It was when our collaborators at LBNL demonstrated electrical control of magnetism in the material that we made that things got super exciting," Schlom said. "Room-temperature multiferroics are exceedingly rare and only multiferroics that enable electrical control of magnetism are relevant to applications."

In electronics devices, the advantages of multiferroics include their reversible polarization in response to low-power electric fields — as opposed to heat-generating and power-sapping electrical currents — and their ability to hold their polarized state without the need for continuous power. High-performance memory chips make use of ferroelectric or ferromagnetic materials. "Our work shows that an entirely different mechanism is active in this new material," Schlom said, "giving us hope for even better — higher-temperature and stronger — multiferroics for the future."

Collaborators hailed from the University of Illinois at Urbana-Champaign, the National Institute of Standards and Technology, the University of Michigan and The Pennsylvania State University. Funding for the work came from the U.S. Department of Energy's Office of Basic Energy Sciences, Division of Materials Science and Engineering. Substrate preparation was performed at the Cornell NanoScale Science and Technology Facility, a member of the National Nanotechnology Coordinated Infrastructure, which is supported by the National Science Foundation (NSF). Electron microscopy support for imaging of the atomic structures was provided by the Cornell Center for Materials Research, a Materials Research Science and Engineering Center also supported by the NSF.



Above: Knight Lab construction specs.
L.B.Knight, Architect.

Engineers Get Under Robot's Skin to Heighten Senses

By Tom Fleischman
Cornell Chronicle
Dec. 8, 2016

Most robots achieve grasping and tactile sensing through motorized means, which can be excessively bulky and rigid. A Cornell group has devised a way for a soft robot to feel its surroundings internally, in much the same way humans do.

A group led by Robert Shepherd, assistant professor of mechanical and aerospace engineering and principal investigator of Organic Robotics Lab, has published a paper describing how stretchable optical waveguides act as curvature, elongation and force sensors in a soft robotic hand. Doctoral student Huichan Zhao is lead author of "Optoelectronically Innervated Soft Prosthetic Hand via Stretchable Optical Waveguides," which is featured in the debut edition of *Science Robotics*. The paper published Dec. 6; Kevin O'Brien and Shuo Li also contributed, both doctoral students in Shepherd's lab.

"Most robots today have sensors on the outside of the body that detect things from the surface," Zhao said. "Our sensors are integrated within the body, so they can actually detect forces being transmitted through the thickness of the robot, a lot like we and all organisms do when we feel pain, for example."

Optical waveguides have been in use since the early 1970s for numerous sensing functions, including tactile, position and acoustic. Fabrication was originally a complicated process, but the advent over the last 20 years of soft lithography and 3-D printing has led to development of elastomeric sensors that are easily produced and incorporated into a soft robotic application. Shepherd's group employed a four-step soft lithography process to produce the core (through which light propagates), and the cladding (outer surface of the waveguide), which also houses the LED (light-emitting diode) and the photodiode.

The more the prosthetic hand deforms, the more light is lost through the core. That variable loss of light, as detected by the photodiode, is what allows the prosthesis to "sense" its surroundings.

"If no light was lost when we bend the prosthesis, we wouldn't get any information about the state of the sensor," Shepherd said. "The amount of loss is dependent on how it's bent."

The group used its optoelectronic prosthesis to perform a variety of tasks, including grasping and probing for both shape and texture. Most notably, the hand was able to scan three tomatoes and determine, by softness, which was the ripest. (Online at http://news.cornell.edu/stories/2016/12/engineers-get-under-robots-skin-heighten-senses)

Zhao said this technology has many potential uses beyond prostheses, including bio-inspired robots, which Shepherd has explored along with Mason Peck, associate professor of mechanical and aerospace engineering, for use in space exploration. "That project has no sensory feedback," Shepherd said, referring to the collaboration with Peck, "but if we did have sensors, we could monitor in real time the shape change during combustion [through water electrolysis] and develop better actuation sequences to make it move faster."

Future work on optical waveguides in soft robotics will focus on increased sensory capabilities, in part by 3-D printing more complex sensor shapes, and by incorporating machine learning as a way of decoupling signals from an increased number of sensors. "Right now," Shepherd said, "it's hard to localize where a touch is coming from."

This work was supported by a grant from Air Force Office of Scientific Research, and made use of the Cornell NanoScale Science and Technology Facility and the Cornell Center for Materials Research, both of which are supported by the National Science Foundation.

Figure 1: Doctoral student Shuo Li shakes hands with an opto-electronically innervated prosthesis. Huichan Zhao/Provided.

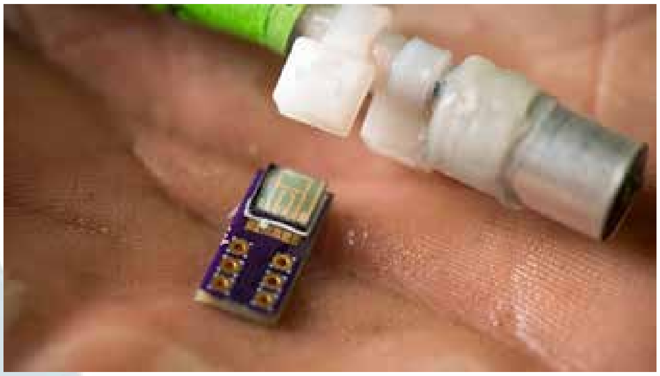


Figure 1: A water sensor technology that began as basic research at Cornell is blooming into a business that fills a vital need for grape, nut, apple and other growers. Cornell-developed water sensor and probe that inserts into the stem or trunk of a plant. Lindsay France/University Photography

Water Sensor Moves from Basic Research to Promising Business

By Krishna Ramanujan
Cornell Chronicle
February 6, 2017

While current water sensing tools are expensive, inaccurate or labor intensive, the new sensor tells growers when their plants need irrigation with accurate, real-time readings at reasonable cost. Much like a blood pressure gauge for humans, this sensor reads the water pressure inside the plant. When plants are thirsty, their water pressure is low, sometimes even negative. The sensor reads this pressure inside the plant to help growers ensure plant health and optimize water use in drought-stricken agricultural areas. Applying water at the right time can also greatly improve the quality of fruits, nuts and especially grapes for red wines. In mid-2016, Cornell engineers and horticulturalists who developed the sensor launched FloraPulse, a startup aimed at commercializing the sensor and using it to provide agricultural services. The first target markets are grape and nut growers in California's Central and Napa valleys.

"We're developing a service for growers to know exactly when, where and how much to irrigate," said Michael Santiago, Ph.D. '16, entrepreneurial lead for FloraPulse and a postdoctoral researcher in the lab of Abraham Stroock, the project's principal investigator. Santiago helped develop the technology while pursuing his doctorate in Stroock's lab.

Continued on page 16

In 2009, Stroock, director of the Robert Frederick Smith School of Chemical and Biomolecular Engineering, and Alan Lakso, professor emeritus of horticulture, began development of a microsensor using new technologies developed in Stroock's lab. The sensor, made in the Cornell NanoScale Science & Technology Facility (CNF), is a silicon chip with a tiny cavity that holds water. When the chip is embedded in a plant with drought stress, water leaves this cavity through a nanoporous membrane and the resulting tension is turned into an electrical signal.

Over the past three years, the Cornell team developed a prototype of a commercial water sensor with a fingertip-sized chip and a probe for inserting into plant stems. The sensor is compatible with electronic plug-and-play readers that are the industry standard for billions of sensors, including tire pressure sensors in today's cars, for example. This compatibility extends to wireless integration that is rapidly transforming agricultural practice.

"That's a crucial piece of our strategy, take a measurement that's hard to get and turn it into something that is very common," said Stroock.

This year, the group will continue to tweak the technology and they will conduct further greenhouse and field testing this spring and summer at Cornell and in California.

"We're going to help make better wines, because there is a strong relationship between water pressure or the stress that we measure and the quality of red wine," Santiago said.

The initial basic research was supported by the United States Department of Agriculture's (USDA) National Institute of Food and Agriculture (NIFA), the National Science Foundation (NSF) and the U.S. Air Force.

From science to business

Though Santiago is trained as a mechanical engineer, he has been teaching himself how to commercialize the sensor. In his fourth year as a graduate student, he participated in eLab, a nonprofit business accelerator for Cornell students. There, he learned to develop a business model and pitch an idea.

In November 2016, the group became one of four university teams to win the first national Innovations in Food and Agricultural Science and Technology (I-FAST) prize competition. The USDA-NIFA prize provided $50,000 to attend an intensive NSF program, Innovation Corps (I-Corps), that supports and guides university scientists to translate their tech innovations into the marketplace.

The grant has been instrumental in developing the business, Santiago said. "The I-Corps program enabled us to interview over 100 potential customers so that we can build our business model using real customer data," he explained. Over a six-week period at the end of 2016, Santiago traveled throughout California's wine country, where he interviewed potential customers.

The group also added MBA student Zachary Leidig, who has taken a leave of absence from Cornell's Samuel Curtis Johnson Graduate School of Management this semester to build the business. Santiago and Leidig will move to California in the next few months.

Together, they are building a business model, talking to potential investors and suppliers, arranging for licensing technology from Cornell's Center for Technology Licensing and testing sensors this spring and summer.

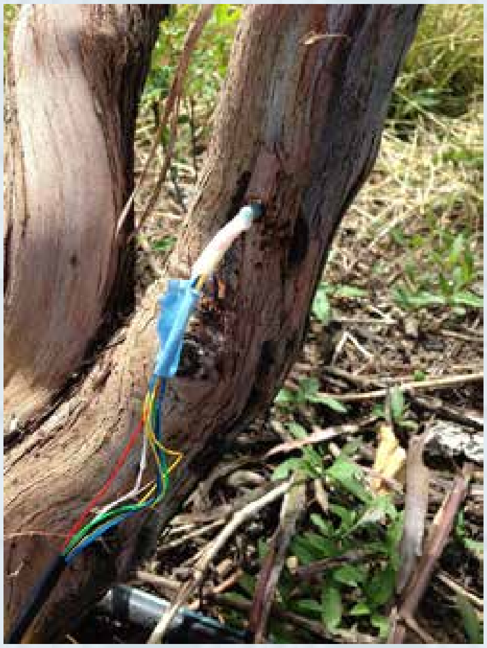


Figure 2: Sensor in grapevine; A sensor installed in the trunk of a grapevine. After the installation of the sensor, the researchers cover and insulate the trunk. Alan Lasko/Provided.

'Bolt of Lightning' Captures Development of Block Copolymer

By Tom Fleischman
Cornell Chronicle
October 18, 2016

The ability to precisely control every aspect of a material, even at the nanoscale, is of critical importance in a host of applications.

One class of such novel materials, block copolymers (BCPs), are being developed today to enable continued advancement of data archiving, as well as advanced drug refinement using protein filters, among other things.

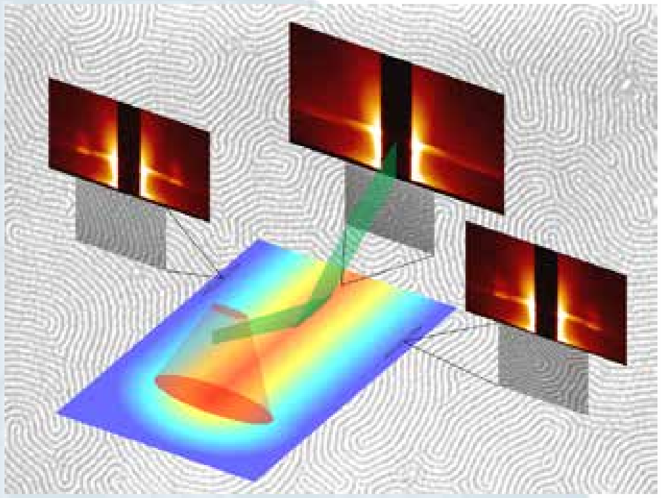


Figure 1: A schematic representation of the experimental and measurement setup for block copolymer phase segregation. Alan Jacobs/Provided.

BCPs are combinations of materials that, like oil and water, don't readily mix in nature, but can be forced to do so through a chemical "marriage" of blocks in a polymer chain. A group of Cornell engineers led by Mike Thompson, M.A. '82, Ph.D. '84, and Chris Ober, professors of materials science and engineering, are exploring how to control these novel materials by capturing the early stages of structure development using laser induced ultra-fast heating and cooling.

Their paper, "Kinetics of Block Copolymer Phase Segregation During Sub-millisecond Transient Thermal Annealing," was published Aug. 22 in the American Chemical Society journal, *Macromolecules*. Alan Jacobs, a graduate student in Thompson's lab, is lead author.

Thompson said that heating these materials for extremely short durations — between 250 microseconds and 10 milliseconds — allows researchers to work with temperatures in excess of 1,000 degrees even in thermally sensitive polymer materials.

"This opens up a whole new regime for studying the dynamics of polymer motion," he said. "Normally we think of polymers as being fairly rigid. But when you go to high enough temperatures, they become exceedingly mobile and flexible in a liquid-like state. With laser induced heating, we can reach these temperatures fast enough, and also cool down fast enough, that the block copolymers can reorder and restructure themselves into useful and interesting structures before they begin to burn."

BCPs order themselves based on the chemistry of their constituent "blocks," commonly referred to as A's and B's. As the two blocks do not want to mix, these materials try to find structures where mixing is minimized.

"If you have approximately the same amount of the A and B materials," Thompson said, "they form layers of A and B. ... All the A blocks try to get next to each other, as do all the B blocks."

But by rapid heating and cooling, these blocks that normally wouldn't get along are forced together by thermal motion, generating unique materials and patterns.

"With enough energy in there," Jacobs said, "they will mix randomly and create a more homogeneous structure at high temperature. Then, as they cool, they are free to adopt the new and unique structures."

In work performed at the Cornell NanoScale Science and Technology Facility and the Cornell Center for Materials Research, and analyzed at the Cornell High Energy Synchrotron Source, the group heated a BCP built from polystyrene (PS) and polymethyl methacrylate (PMMA), using a laser spike annealing apparatus to temperatures up to 550°C (more than 1,000 F) for durations no longer than 10 milliseconds.

The material did not degrade during that extremely short anneal time, but instead was put

Continued on page 18

in a state of controlled disorder, which could be tuned by varying both the duration of the heating and the peak temperature. Although perhaps counterintuitive, this controlled disorder results in a final material that has fewer defects and unique properties, which can be "designed" by both the underlying chemistry and the annealing.

The group is, in essence, capturing a moment in time by hitting the BCP with a "bolt of lightning." Future work is focused on understanding the details of the process. "We've shown that we can get fewer defects using this really rapid heating to initially do phase segregation, but we don't yet know why," Jacobs said. "But this gives us a good start, a good idea of what's going on in those initial stages."

This work was supported by grants from the U.S. Department of Defense, the National Science Foundation and the National Institutes of Health.

Cancer Cells 'Talk' to Their Environment, and It Talks Back

By Tom Fleischman
Cornell Chronicle
November 21, 2016

Interactions between an animal cell and its environment, a fibrous network called the extracellular matrix, play a critical role in cell function, including growth and migration. But less understood is the mechanical force that governs those interactions.

A multidisciplinary team of Cornell engineers and colleagues from the University of Pennsylvania has devised a method for measuring the force a cell — in this case, a breast cancer cell — exerts on its fibrous surroundings.

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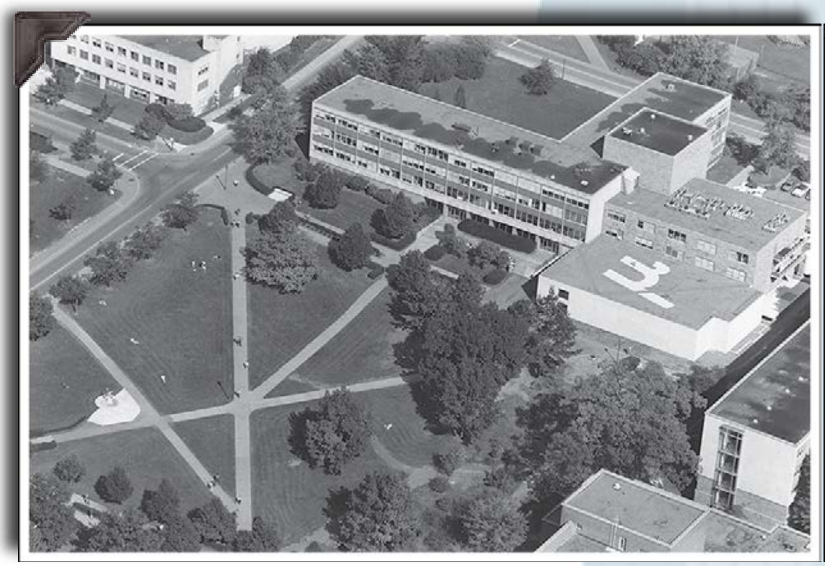


The Knight Lab Dedication brought many participants to campus — an aerial view shows the "µ" on the roof.
Special guests for the dedication included the Ballantynes, left, the Knights, middle, and President Rhodes, right.
Our first two directors, Edward Wolf and Harold Craighead, pose with the portrait of Lester B. Knight, Jr.
All photographs by University Photography.

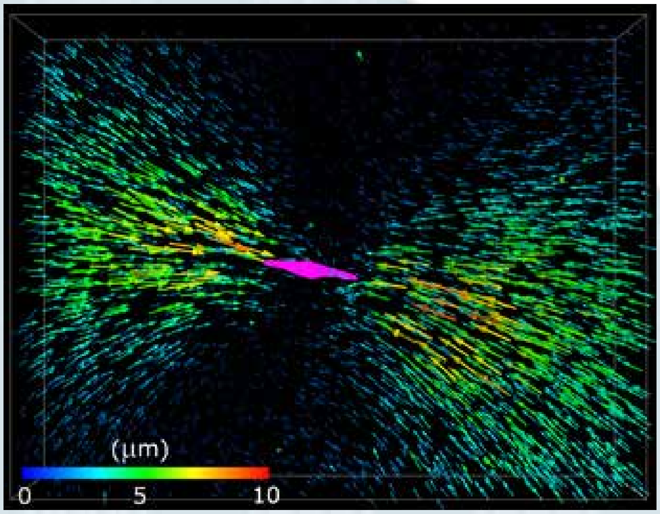


Figure 1: The above image shows the measurement of single-cell traction force using gel deformation and a fibrous nonlinear elastic model. Each arrow represents the discrete displacement of a fluorescent bead bonded to a collagen fiber. Matthew Hall/ Provided. (See cover also!)

Understanding those forces has implications in many disciplines, including immunology and cancer biology, and could help scientists better design biomaterial scaffolds for tissue engineering.

The group, led by Mingming Wu, associate professor in the Department of Biological and Environmental Engineering, developed 3-D traction-force microscopy to measure the displacement of fluorescent marker beads distributed in a collagen matrix. The beads are displaced by the pulling of migrating breast cancer cells embedded in the matrix. An important part of the puzzle was to calculate the force exerted by the cells using the displacement of the beads. That calculation was carried out by the team led by Vivek Shenoy, professor of materials science and engineering at the University of Pennsylvania.

The group's paper, "Fibrous nonlinear elasticity enables positive mechanical feedback between cells and extracellular matrices," was published online Nov. 21 in Proceedings of the National Academy of Sciences. Matthew Hall, Ph.D. '16, now a postdoctoral researcher at the University of Michigan, is lead author and engineered the collagen matrices used in the study.

Wu — who also was affiliated with the Cornell Center on the Microenvironment and Metastasis at Weill Cornell Medicine, which existed from 2009 through 2015 — said the group's work centered on a basic question: How much force do cells exert on their extracellular matrix when they migrate? "The matrix is like a rope, and in order for the cell to move, they have to exert force on this rope," she said. "The question arose from cancer metastasis, because if the cells don't move around, it's a benign tumor and generally not life-threatening."

It's when the cancerous cell migrates that serious problems can arise. That migration occurs through "cross-talk" between the cell and the matrix, the group found. As the cell pulls on the matrix, the fibrous matrix stiffens; in turn, the stiffening of the matrix causes the cell to pull harder, which stiffens the matrix even more. This increased stiffening also increases cell force transmission distance, which can potentially promote metastasis of cancer cells.

"We've shown that the cells are able to align the fibers in their vicinity by exerting force," Hall said. "We've also shown that when the matrix is more fibrous — less like a continuous material and more like a mesh of fibers — they're able to align the fibers through the production of force. And once the fiber is aligned and taut, it's easier for cells to pull on them and migrate."

"I'm a strong believer that every new science discovery goes hand-in-hand with new technology development," she said. "And with every new tool, you discover something new."

This research was supported by grants from the NIH, the NCI and the NSF, and made use of the CNF, the Cornell Biotechnology Resource Center Imaging Facility, CCMR and NBTC.

Below: A well-known view into the old Knight Lab cleanroom. Photographer unknown.

2016 CNF Whetten Memorial Award Winner:

E. Rose Agger

Provided.

Rose Agger is graduating from Cornell in May 2017 with as M.S. in Electrical and Computer Engineering (ECE). She is the recipient of the 2016 CNF Nellie Yeh-Poh Lin Whetten Award. The Whetten Award recognizes an outstanding female graduate student who shows spirit and commitment to professional excellence, as well as professional and personal courtesy.

Before Cornell, Rose completed two bachelor's degrees: a B.A. in Neuroscience and Film Studies at Wesleyan University (2010), and a B.S. in ECE at the University of Maryland, College Park (2013). She made the seemingly strange transition because she decided she wanted to create electronic devices to improve and accelerate neuroscience research.

In August 2013, she joined the Molnar Group at Cornell, which develops electronic neural interfaces as well as imagers and RF integrated circuits (ICs). Rose's research interests include CMOS circuit design and packaging for neural recording and imaging devices. Rose's first project was the design of a clean room packaging procedure to facilitate biological testing using imaging chips. ICs with 3D time-resolved imaging capabilities can image microorganisms and other biological samples given proper packaging. A portable, flat, easily manufactured package would enable scientists to place biological samples on slides directly above the Molnar group's imaging chip.

Rose developed a packaging procedure using laser cutting, photolithography, epoxies, and metal deposition. Using a flip-chip method, she verified the process by aligning and adhering a sample chip to a holder wafer (Figure 1).

Rose's thesis project is the circuit design and packaging procedure for an NIH-funded neural implant, called a microscale optoelectronically transduced electrode (MOTE).

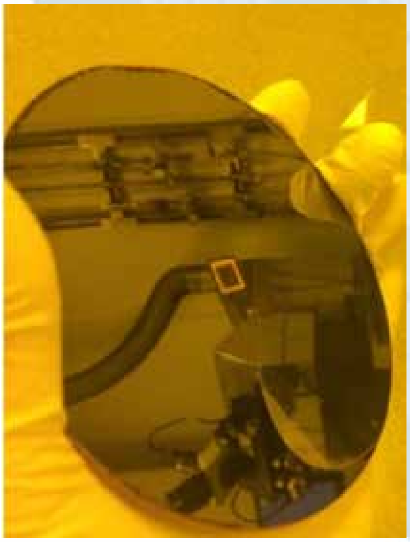
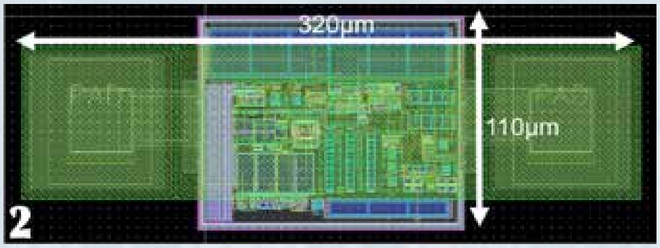


Figure 1: A sample imager chip packaged in a carrier Si wafer.

Neural recording implants for mice have greatly advanced neuroscience, but they are often damaging and limited in their recording location.

This project will result in free-floating implants that cause less damage, provide rapid electronic recording, and increase range of recording across the cortex. A low-power silicon IC containing amplification and digitization sub-circuits is powered by a dual-function gallium arsenide photovoltaic and LED (Figures 2, 3).

Through thin film deposition, photolithography, and chemical and physical etching, the Molnar Group and the McEuen Group (Applied and Engineering Physics department) will package the IC and LED into a biocompatible implant approximately 100 µm^3. The IC and LED are complete and we have begun refining this packaging procedure in the Cornell NanoScale Science & Technology Facility.



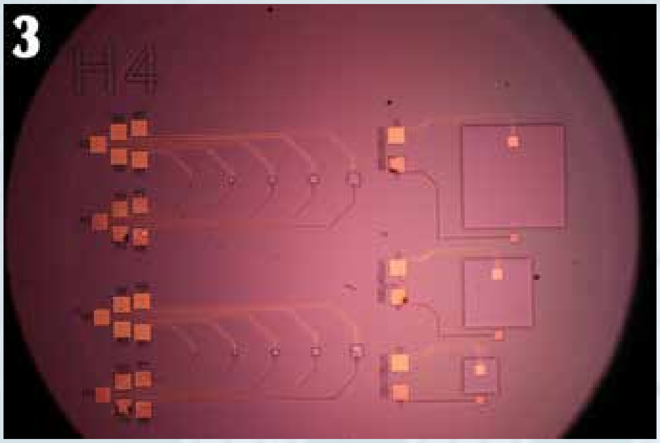


Figure 2, above: Si IC design of neural MOTE. Figure 3, below: GaAs LEDs fabricated in CNF by A. Cortese, McEuen Group.

As a CNF Fellow, Rose has worked on a long-term metal-insulator-metal (MIM) capacitor characterization project. Former Fellow and continuing CNF user, Kwame Amponsah, developed the original procedure for the capacitor fabrication, and another former fellow, Jonilyn Longenecker, revised the procedure and began the arduous process of characterization. MIM caps are useful to clean room users as testing devices to verify electronic characteristics of their active circuitry. This project's objective is to determine differences in current-voltage (IV) and capacitor-voltage (CV) relationships across variations in capacitor size and dielectric type. This effort requires an approximately 20-step process repeated for two-to-six varieties (dependent on temperature and thermal versus plasma options) of the following dielectrics: HfO_2, SiO_2, Al_2O_3, TaO_x, and TiO_2.

In addition to her research pursuits, Rose is involved with many groups committed to outreach and improving the graduate community. As the Director of the Graduate Society for Women Engineers at Cornell, she coordinates outreach events to promote STEM careers among local youth, organizes professional development talks for graduate engineers, and runs social activities to engage and support diverse graduate engineers. She also participates in STEM outreach as a CNF Outreach Ambassador and a volunteer with Destination Imagination. Rose is a founding member of the Graduate and Professional Students for Sexual Violence Prevention, which designs consent and bystander programming that targets graduate students in all departments.

In January. CNF Outreach Ambassador Agger helped out with judging the CNF FIRST Lego Expo (more on page 34). Photo by Don Tennant.

Rose would like to extend her sincere thanks to the CNF staff for their support and encouragement throughout her Cornell journey. As a Tech Mentor at Rev Ithaca Startup Works and beyond, she will continue to apply the hard work, patience, and courtesy she learned at the CNF.

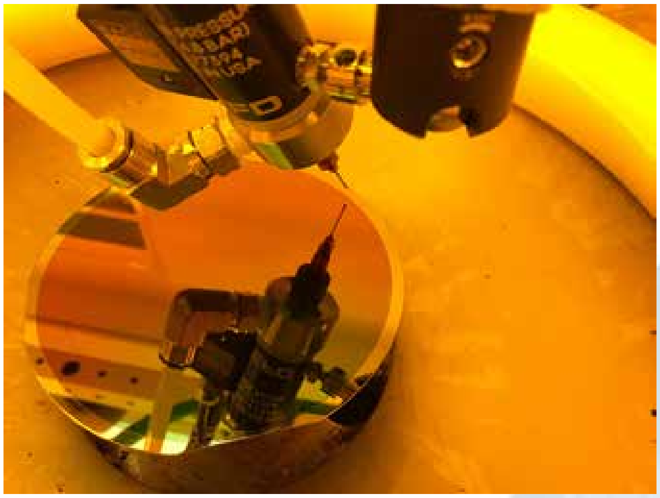
Photograph provided by Tim Whetten

Nellie Yeh-Poh Lin Whetten; CNF Memorial Award

This award is given in fond memory of Nellie Whetten (pictured above) — a CNF staff member from 1984 to 1987 who died on March 24, 1989. This award recognizes outstanding young women in science and engineering whose research was conducted in the CNF, and whose work and professional lives exemplify Nellie's commitment to scientific excellence, interdisciplinary collaboration, professional and personal courtesy and exuberance for life. In the words of her husband, Dr. Timothy Whetten,

> "The award should remind us to find out what it is like for people different from us to live and work in the same community. For men, to try to appreciate what it is like to be a woman scientist. For Caucasians, to try to feel what it is to be Asian or Black. For members of racial minorities and women, to try to understand what it is like to be a white male. And finally, the award should stimulate each of us to reach out and encourage women scientists who, like Nellie have the brilliance, stubbornness, and cheerfulness to succeed."

http://www.cnf.cornell.edu/cnf_whetten.html lists all the CNF Whetten Memorial Award Winners



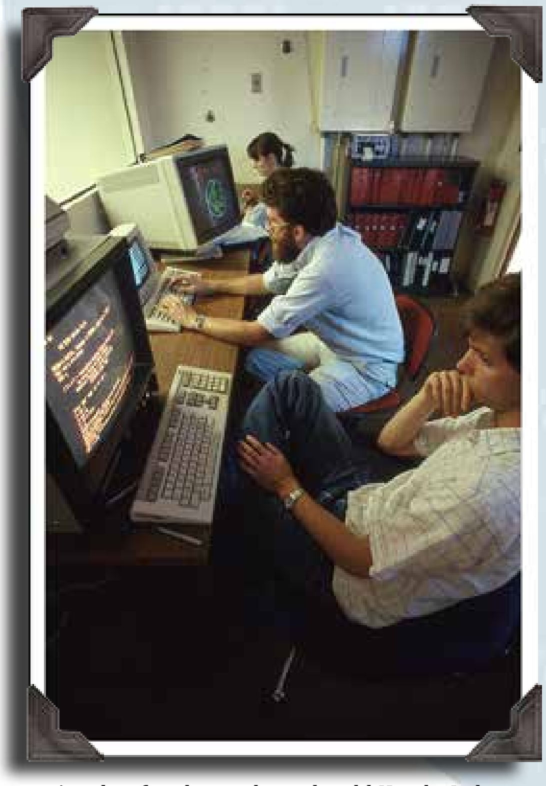
Edge Bead Removal System

CNF has installed an Edge Bead Removal System in the Photolithography Spinner room. This system uses a Brewer Science Cee Model 200 Flange Spinner platform along with a Nordson 752 Series Diaphragm Dispense Valve with their patented BackPack valve actuator controlled by their ValveMate 8000 Controller. The dispense nozzle is mounted on a 4-axis cantilevered T-Slot arm with a position micrometer on the X-axis for adjusting the bead size. It utilizes Microposit EBR 10A (PGMEA) as a solvent. This setup can accommodate 51 mm to 150 mm size substrates, and the default setting is 100 mm.

An EBR recipe is pre-programmed consisting of the following process steps: Step 1: 300 RPM [Speed], 400 RPM/Sec [Acceleration], 20 Sec [Step Time], #2 [Dispense 18 seconds]; Step 2: 2000 RPM [Speed], 1400 RPM [Acceleration], 15 Sec [Step Time]. Note that the user might need to run this recipe multiple times depending on the thickness of the resist. The clean edge prevents failure and contamination in exposure, reactive ion etch, and thin film deposition.

For more information, speak to Garry Bordonaro or Ed Camacho.

(bordonaro@cnf.cornell.edu, camacho@cnf.cornell.edu)



Another familiar sight in the old Knight Lab — the CAD room. Photographer unknown.

New Processes and Equipment

RF/DC Cosputtering is now available on the AJA sputter deposition system.

We now have the ability to sputter one RF material and one DC material at the same time. This is a process that has been requested by the user committee and several of the users in the lab. Users will be able to deposit multiple materials at independent power levels in order to tune deposition rates of the independent targets. This process was developed by myself and David Lynch—Thank You, David Lynch!! Users can see me for training.

The Oxford Cobra etch system is now open to the user community. The Oxford tool has HBr gas chemistry and will enable the use of the new photonics etch developed by Vince Genova. The tool also has chlorine and methanol gas chemistries. Please see the updates on teh Cobra system later in this issue. Users can see Jeremy Clark, Vince Genova or me for training.

Best Regards, Tom Pennell
(pennell@cnf.cornell.edu)

TEOS Available on Oxford PECVD

TEOS is now available on the Oxford 100 PECVD system. TEOS is used instead of silane to deposit SiO_2 films in PECVD to have good conformal step coverage. SiO_2 TEOS process has been characterized including deposition rate and film stress at different temperature, pressure and LF power. Characterization results can be found on the CNF User Process Wiki.

If you have any questions, please contact staff member Xinwei Wu, wu@cnf.cornell.edu.

Thermal Nanoimprint Lithography (TNIL): An Enabling Technology for MEMS and Nanophotonics

Vincent J. Genova: CNF Research Staff, Cornell University, Ithaca, NY 14853
Chengyu Liu: CNF Fellow, School of Applied and Engineering Physics, Cornell University, Ithaca, NY 14853

Introduction:

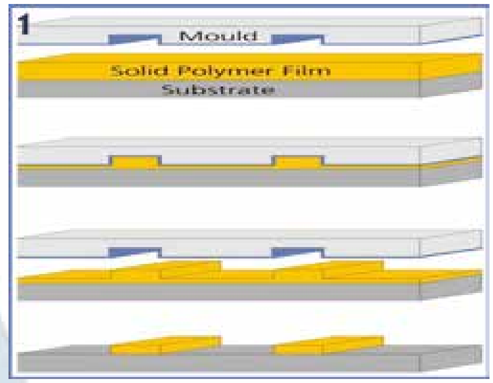
Nanoimprint lithography (NIL) is an emerging technology that has the advantage of high throughput with sub-10 nm resolution. The resolution is largely governed by the feature dimensions of the master or template, which can be defined by advanced photolithography or electron-beam lithography. NIL has been a strategic method on the ITRS roadmap for the 45 nm node and below. In addition to electronics, NIL can be a benefit to many applications including nanophotonics, biotechnology, displays, and microelectromechanical systems.

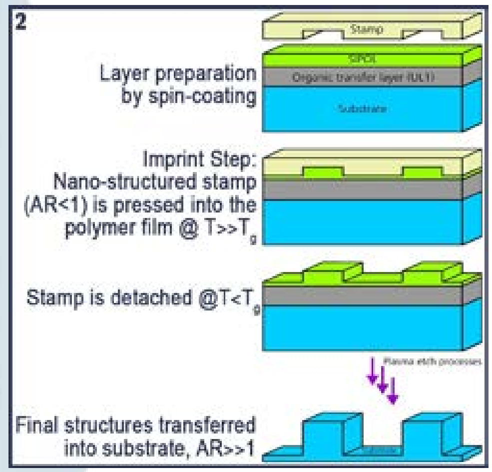
In this study, we evaluated two new thermal imprint resists from Microresist Technology on our Nanonex NX-2500 imprint tool. Both single layer and bilayer resist systems were studied and the removal of residual resist was optimized with proper plasma etch chemistry and parameters. We then demonstrated effective pattern transfer into both silicon and silicon-based dielectrics using advanced ICP based reactive ion etching. The bilayer resist system was also used to demonstrate liftoff, an additive processing scheme.

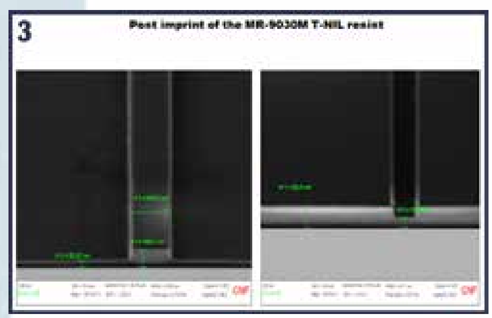
Experimental:

The Nanonex NX-2500 has both thermal imprint (TNIL) and photocurable imprint (PNIL) capabilities. The thermal imprint module can reach a temperature of 300°C with rapid heating and cooling rates. The silicon template containing a bright and dark field line space pattern was defined with the ASML DUV (248nm) stepper producing a minimum feature size of 250 nm. The lithographically defined pattern was then transferred into the silicon with SF_6/C_4F_8 mixed chemistry in the Plasma-Therm SLR ICP 770. This etch produces smooth and perfectly anisotropic sidewall profiles, which are essential for optimum imprint replication. The template is coated with FOTS in the MVD system to prevent the adherence of the resist in the imprint process. The two Microresist Technology TNIL resist systems evaluated were the MR-9030M single layer resist, and the SIPOL/UL1 bilayer system with the SIPOL having a silicon concentration and the UL1 being a purely organic transfer layer. The single layer imprint process is illustrated in Figure 1, where the pattern is imprinted at a temperature of 120°C, well above the glass transition temperature T_g.

Residual layer etching is performed in the Oxford Plasmalab 80 using oxygen at low pressure and low power to retain critical dimensions and minimize the loss of resist. The imprinted patterned silicon wafers were etched with the Bosch® deep silicon etch and the mixed SF_6/C_4F_8 etch in the Plasma-Therm SLR







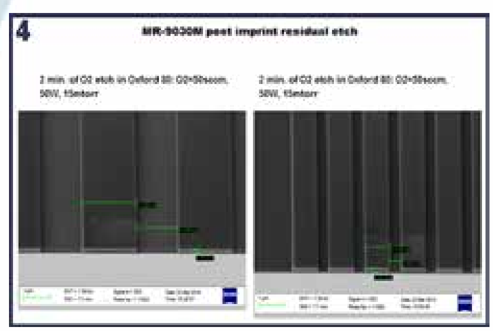


Figure 1: MR-9030M TNIL process overview.
Figure 2: SIPOL/UL1 TNIL process overview.
Figure 3: Post imprint residual thickness variation of MR-9030M TNIL resist.
Figure 4: MR-9030M residual etch in O_2.

ICP. An additional wafer was etched with HBr in the Oxford Cobra NGP ICP. The Bosch etch is commonly used in the fabrication of MEMS devices, while the mixed etch and the HBr etch are used for nanophotonics based devices. An overview of the SIPOL/UL1 bilayer imprint scheme is depicted in Figure 2.

The bilayer stack is imprinted at 140°C at 400 psi for two minutes. The residual silicon containing SIPOL layer is etched with CF_4 in the Oxford Plasmalab 80. The organic underlayer UL1 is etched selectively and anisotropically with an oxygen plasma at low pressure and low power, with the SIPOL serving as a protective mask. The bilayer system was used to imprint onto silicon, silicon dioxide, and low stress silicon nitride substrate layers. Pattern transfer into silicon was demonstrated using the Bosch etch, the mixed SF_6/C_4F_8 etch, and the HBr etch in the above-mentioned systems. Pattern transfer into SiO_2 and Si_3N_4 was accomplished in the Oxford Plasmalab 100 ICP using C_4F_6/He and CH_2F_2/He chemistries. These dielectric etches are used in the fabrication of oxide and nitride based nanophotonics devices here at CNF.

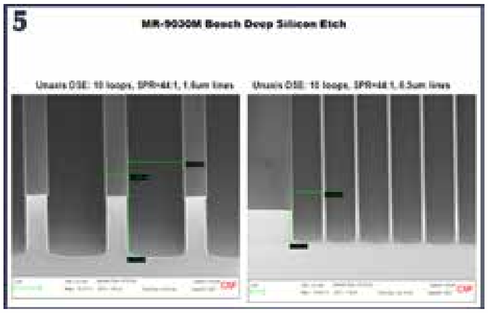
Results for the MR-9030M TNIL Resist:

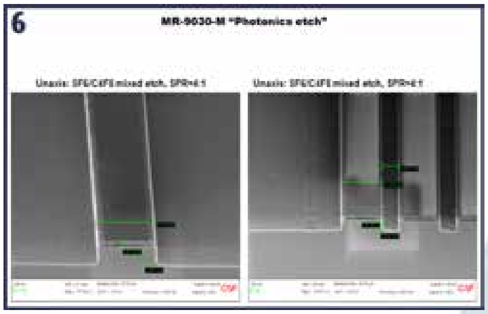
The post imprint residual layer thickness is largely dependent on the feature size and the pattern density as shown in Figure 3. The residual resist is etched in an O_2 plasma at 75W and 20 mtorr resulting in a very anisotropic profile with critical dimensions retained, as shown in Figure 4. Figure 5 illustrates the pattern transfer into silicon using the Bosch deep silicon etch. The selectivity to the MR-9030M is 44:1 on lines as small as 500 nm. The results of the mixed SF_6/C_4F_8 etch and the HBr etch are shown in Figures 6 and 7, respectively. These etches produce anisotropic and smooth sidewalls, which are essential for silicon nanophotonics based devices.

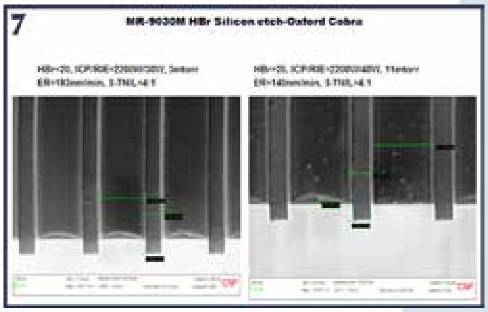
Results for the SIPOL/UL1 Bilayer TNIL Resist System:

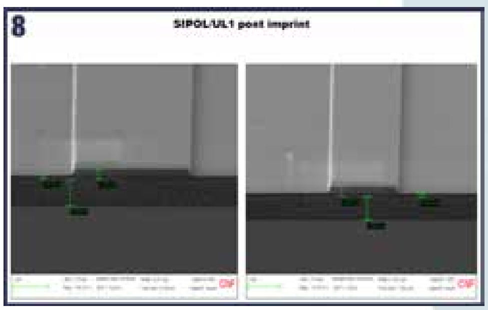
The post imprint residual SIPOL layer thickness is again very dependent on feature size and feature density as shown in Figure 8. Since SIPOL is a silicon containing resist, the residual layer is etched in CF_4 in a low power, low pressure regime to minimize its loss so as to be an effective masking layer for the underlayer etch. The residual SIPOL layer etch is shown in Figure 9.

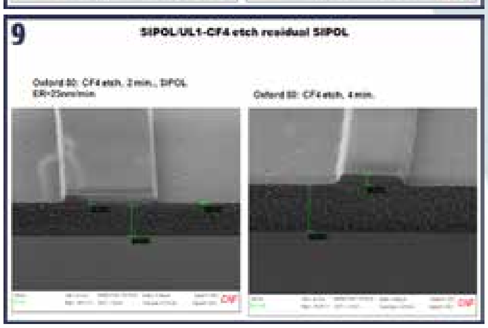
Pattern transfer into the UL1 underlayer is accomplished with a very directional highly selective low power O_2 etch. Selectivity of the UL1 to SIPOL of 13:1 allows for high aspect ratio patterning as shown in Figure 10.











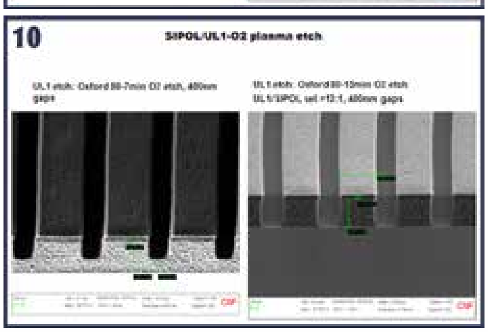


Figure 5: Bosch Si DRIE using the MR-9030M resist.

Figure 6: SF_6/C_4F_8 mixed etch for nanophotonics applications.

Figure 7: HBr silicon waveguide etch.

Figure 8: Post imprint SIPOL residual layer.

Figure 9: CF_4 etch of the residual post imprint SIPOL layer.

Figure 10: Highly selective UL1:SIPOL transfer etch.

Pattern transfer into silicon is achieved with the Bosch DRIE, mixed SF_6/C_4F_8, and HBr etches as shown in Figures 11, 12, and 13, respectively.

The results of the Bosch etch are impressive with a selectivity of 120:1 and an aspect ratio of 14:1 on 800 nm lines. The mask undercut is minimal and the CDs are preserved.

The mixed etch using the SF_6/C_4F_8 produced highly anisotropic and smooth sidewalls with selectivity equivalent to that of thermal oxide.

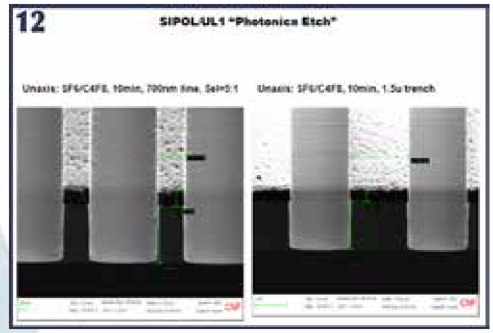
Much like the mixed etch, the HBr-based silicon etch produced smooth straight sidewalls with favorable selectivity. These results demonstrate the suitability of these etches for nanophotonics applications.

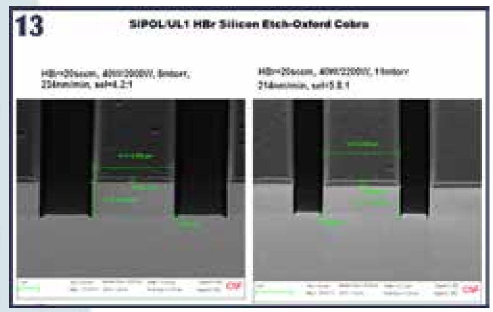
While we have demonstrated successful pattern transfer into silicon with three different approaches, we extended the pattern transfer capability to include silicon-based dielectric films such as SiO_2 and low stress Si_3N_4. Using newly developed dielectric etch processes incorporating highly polymerizing and highly selective plasma chemistries with very low F/C ratio, we applied this to the SIPOL/UL1 bilayer system on a 1 µm silicon dioxide film. The initial application was with C_4F_6/He and this result is shown in Figure 14. This oxide etch produced highly anisotropic and smooth sidewalls with selectivities as high as 22:1 to the bilayer resist. Typical deep UV resists demonstrate a 4-5:1 selectivity with the C_4F_6/He process, so the result with this TNIL bilayer system is quite impressive, allowing us to extend the etch to very high aspect ratio features.

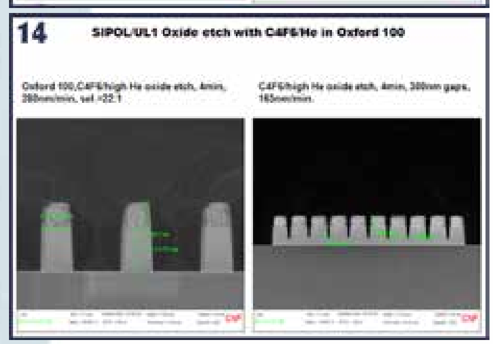
The second application was that of CH_2F_2/He to etch the silicon dioxide and the result is shown is Figure 15. This chemistry produced an etch again with very straight and smooth sidewalls, with selectivity in the range of 13:1. This exceeds selectivities of 4:1 with conventional deep UV resists, enabling the etch to reach even higher aspect ratios. Using the same CH_2F_2/He plasma chemistry in the Oxford 100 ICP, we etched through approximately 750 nm of low stress LPCVD silicon nitride as shown in Figures 16, 17, and 18.

The silicon nitride etch in CH_2F_2/He displays zero RIE-LAG when comparing closely packed 0.5 µm features to widely isolated features. This is in contrast to the C_4F_6/He, which is much more susceptible to RIE-LAG due to the higher polymerizing potential of the precursor. The nitride etch demonstrates smooth and perfectly anisotropic sidewalls with selectivity in the range of 3.5:1, which is comparable to the performance of conventional deep UV resists.

Since many photolithographic bilayer resist systems have been traditionally used in additive processing schemes such as liftoff, we explored the feasibility of using the nanoimprint bilayer SIPOL/UL1 for liftoff. For liftoff to be successful, the resist profile must be undercut in a retrograde profile to provide adequate







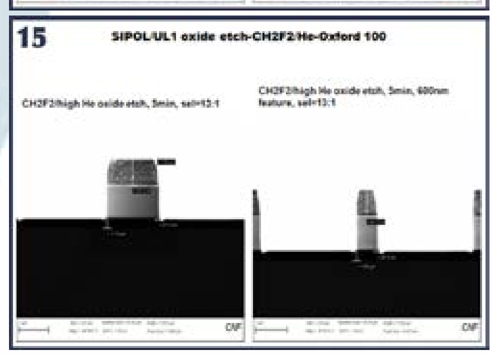


Figure 11: SIPOL/UL1 Bosch DRIE Si etch.

Figure 12: SIPOL/UL1 SF_6/C_4F_8 mixed etch.

Figure 13: SIPOL/UL1 HBr waveguide etch.

Figure 14: 1 µm SiO_2 etch using C_4F_6/He in the Oxford 100 ICP.

Figure 15: 1 µm oxide etch using CH_2F_2/He in the Oxford 100 ICP.

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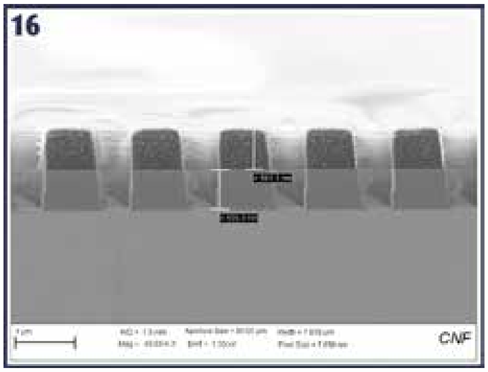

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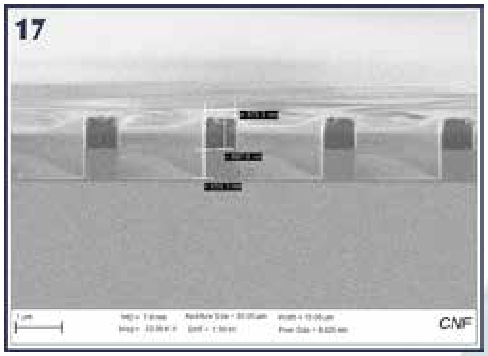

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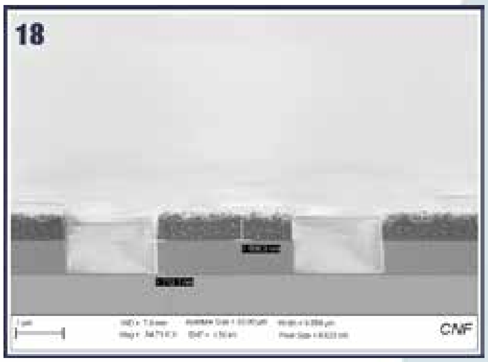

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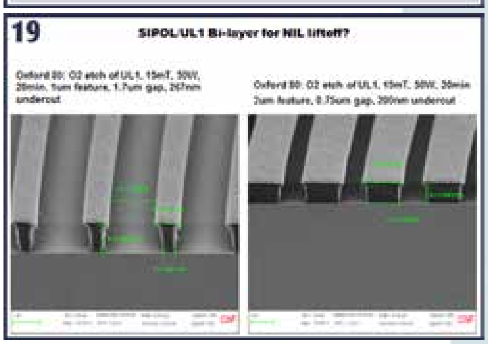

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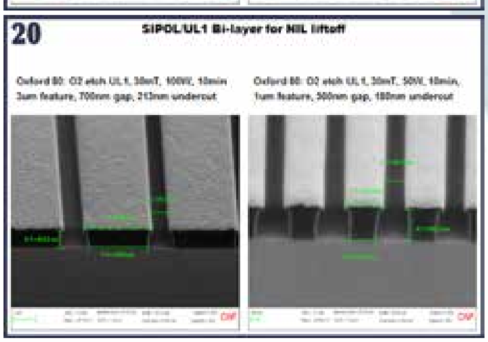

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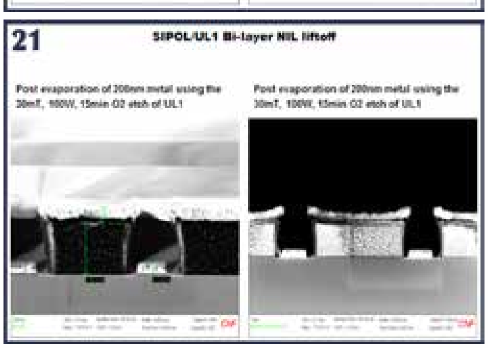


separation of the deposited metal film from the contour of the resist. For the SIPOL/UL1 system, the underlayer UL1 must be etched in a more isotropic manner to provide the desired profile. Therefore, one must use an oxygen plasma at a higher pressure (30mT) and/or at a low power (50W) to increase the radical-to-ion ratio, making the etch less directional. This is illustrated in Figures 19 and 20 where undercut dimensions range from 180 nm to 267 nm, depending on plasma parameters and feature size and spacing.

These retrograde profiles provided the stencil for directional electron beam evaporation of approximately 200 nm of metal with the results depicted in Figure 21.

The results show a clear separation of the deposited metal from the etched bilayer sidewalls, which is crucial for successful liftoff applications.

Conclusions:

The single layer MR-9030M and bilayer SIPOL/UL1 TNIL resists from Microresist Technology together with the Nanonex NX-2500 display a reasonably large process latitude making the thermal imprint process very amenable to a wide variety of applications. We have demonstrated that both resists can be enabling technologies for MEMS and photonics based devices. Specifically, the resists show excellent performance in a variety of etch chemistries in the case of pattern transfer through silicon and silicon based dielectrics. Finally, we have demonstrated successful additive processing via liftoff, with proper tailoring of the bilayer resist profiles.

Figure 16: CH_2F_2/He LPCVD Si_3N_4 etch in the Oxford 100 using SIPOL/UL1 0.5 µm spaced features.

Figure 17: CH_2F_2/He LPCVD Si_3N_4 etch in Oxford 100 using SIPOL/UL1.

Figure 18: CH_2F_2/He Si_3N_4 etch in the Oxford 100 using SIPOL/UL1.

Figure 19: Isotropic etch of UL1 with undercuts ranging from 200-267 nm.

Figure 20: Isotropic etch of UL1 with undercuts ranging from 180-213 nm.

Figure 21: As-deposited metal on the isotropically etched SIPOL/UL1 bilayer.

The CNF Staff Directory, circa 1980. Photographer unknown.

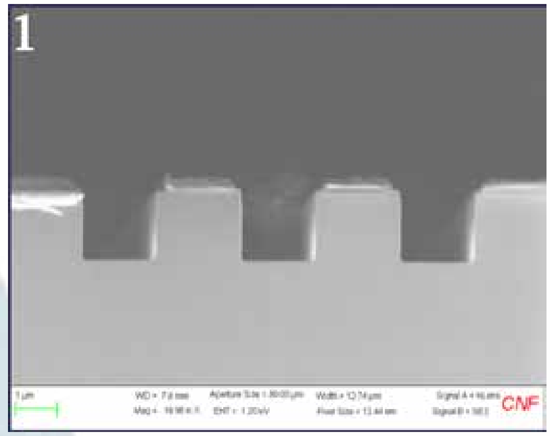
Update on the PlasmaPro 100 Cobra ICP etch system

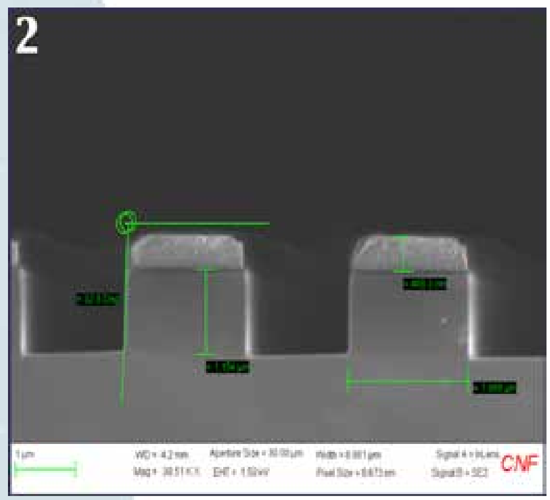
Submitted by: Vince Genova

CNF is pleased to announce newly developed processes on the Oxford Cobra ICP. This inductively coupled plasma (ICP) based reactive ion etch platform is configured for state of the art nanoscale etching. One of the many features of the system includes a wide range temperature (-150°C-400°C) electrode, which will greatly enhance our spectrum of materials that can be etched with volatile chemistries. Mechanical clamping along with high pressure helium backside cooling will allow for additional temperature control for longer etches with resist masking. A low frequency (350 kHz) bias capability of the lower electrode will allow us to more effectively etch high aspect ratio features with minimum RIE-lag effects. The system is equipped with a 12-line gas pod permitting a wide range of process gases and additives for maximum system versatility. The initial setup includes the following gases: HBr, Cl_2, BCl_3, CH_3OH, SF_6, O_2, H_2, and Ar. Future additions may include C_4F_8, CF_4, N_2, and He as process gases. The system is constructed for corrosive halogen based gases and is equipped with a load lock for sample entry and system isolation. The tool also has an Ocean Optics optical emission spectrometer (OES) fully integrated to the Spectrasuite software that will allow users to monitor chamber conditions and process chemistry for consistent and repeatable etch results, which are often a challenge in a multi-user facility.

One of the main missions of the new Oxford Cobra ICP is nanoscale etching of silicon with HBr-based chemistry. The benefits of HBr etching of silicon have been known for many years and these include moderately fast etch rates with a highly anisotropic etch profile due to its ion enhanced etch mechanisms. HBr chemistry offers the flexibility of using either resist or SiO_2 as etch masks and the ability to etch high aspect ratio nanoscale features without many of the artifacts that are present in chlorine based plasmas such as trenching. There are many differences between HBr and chlorine chemistries that can manifest effects in etch rates, selectivity, and artifacts such as microtrenching. For example, the surface adsorption coverage of chlorine is at least 1.6 times higher than that of Br, which can contribute to increased microtrenching. Ion fluxes in HBr plasmas are typically 40% less than those in chlorine based plasmas at equivalent conditions, leading to higher selectivity to both resist and silicon dioxide. These process attributes will greatly enhance our capabilities to fabricate advanced silicon photonic, MEMS, and electronic devices.

Our HBr based silicon etch results have demonstrated etch rates exceeding 200 nm/min and selectivities exceeding 5:1 and 20:1 for DUV resists and silicon dioxide masks respectively as shown in the following Figures 1-3.





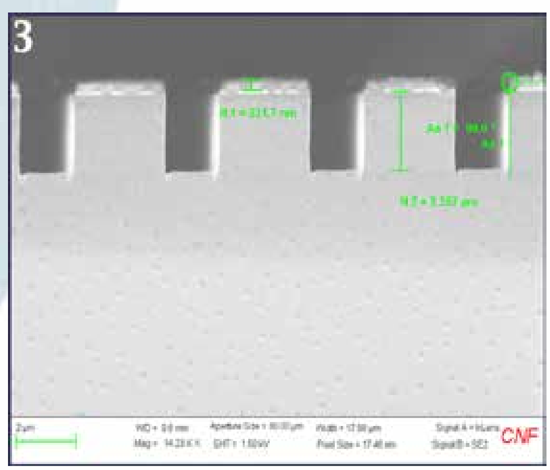
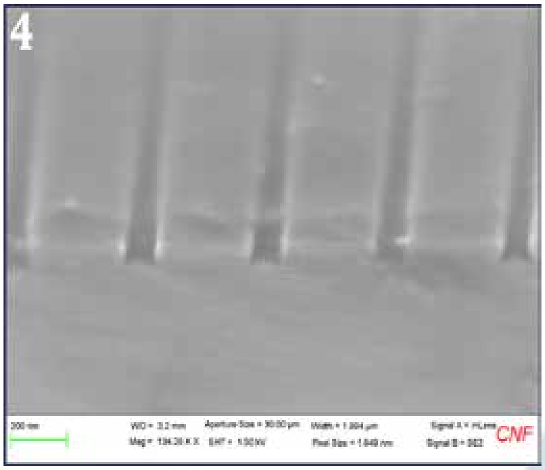
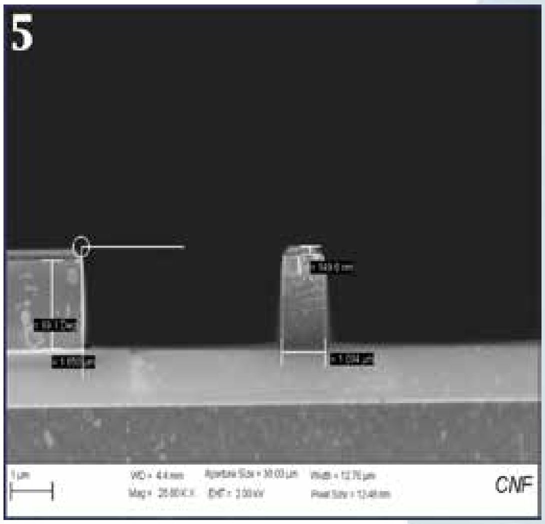


Figure 1: HBr/Ar, UV210 PR, sel: 5:1, 180 nm/min.
Figure 2: HBr/Ar, UV210 PR, sel. 5:1, 135 nm/min.
Figure 3: HBr, SiO_2 mask, sel. 22:1, 230 nm/min.





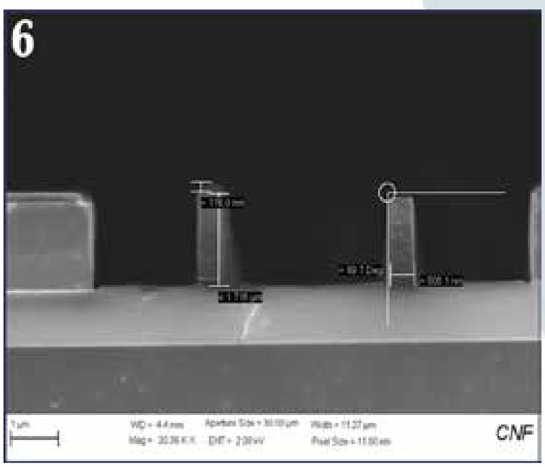


Figure 4: HBr/Ar, ZEP sel.3:1, 95 nm/min.
Figure 5: HBr/Ar, 27:1 BOX sel., 135 nm/min.
Figure 6: HBr/Ar, 27: 1 BOX sel., 135 nm/min.

Figure 4 illustrates pattern transfer using e-beam lithography with ZEP resist on 75 nm features.

Much of the silicon photonics based work is done on silicon on insulator (SOI) based structures, where strict requirements on sidewall smoothness, anisotropy, and high selectivity to the buried oxide (BOX) layer are imperative for meeting minimum loss specifications. Figures 5 and 6 illustrate results achieved on SOI structures patterned with UV210 DUV resist.

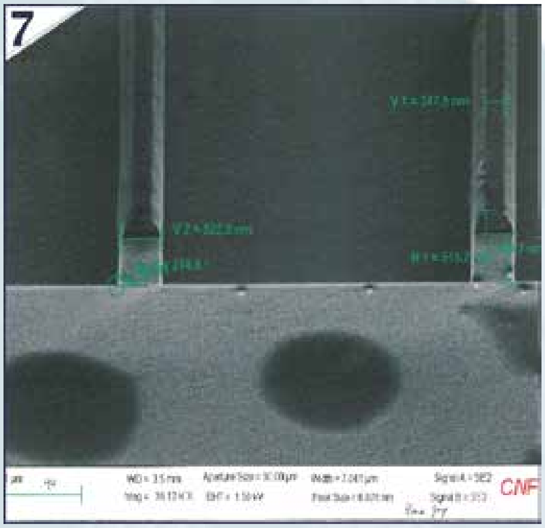
The Oxford Cobra ICP also offers the option of using a low frequency 350 kHz bias capability of the lower electrode. This effectively changes the electron energy distribution of the plasma which directly affects the ion energies. RIE-LAG is characterized by a significant difference in etch rate among features with relatively wide and small dimensions, and is often due to the inability of reactant species to travel down narrow and deep features. By increasing the ion concentration and ion energies, RIE-LAG can be minimized with the proper choice of plasma parameters. Figures 7 and 8, opposite page, illustrate HBr etching of 4 µm and 800 nm gap silicon features respectively defined with the ASML and etched with low frequency HBr/Ar chemistry.

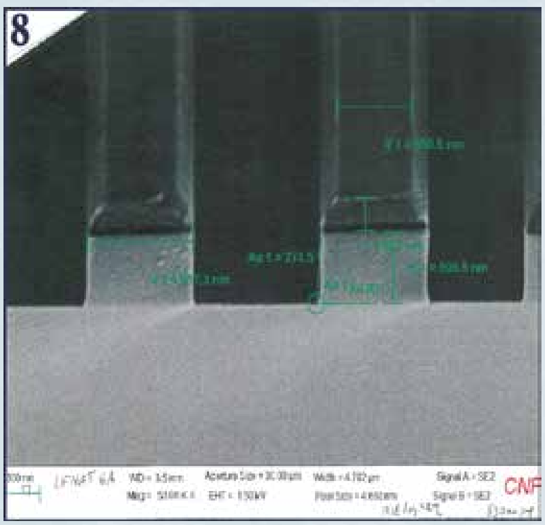
The application of low frequency minimized the RIE-LAG to less than 2% for a depth of 500 nm.

There is also considerable interest among the Cornell faculty and government labs in diamond etching, whether it be single crystal diamond, nanocrystalline diamond, or diamond-like carbon (DLC). The fabrication of diamond based nanophotonic and nanomechanical devices have shown great results and potential. In response to this need, the CNF has developed a diamond etch in the Oxford Cobra ICP using $O_2/SF_6/Ar$ based chemistry. We specifically worked on ultra-nanocrystalline diamond (UNCD) films that are increasingly used in MEMS sensors and actuators, especially those with a need for high biocompatibility. The addition of a small percentage of SF_6 to a largely O_2 plasma leads to a smooth etch morphology since UNCD films are composed of nanograins that can induce large surface roughness. The SF_6 assists in the preferential etching of amorphous carbon at intergrain boundaries. Figure 9 illustrates a deep (>10µm) etch into UNCD resulting in an etch rate exceeding 270 nm/min with a selectivity to an aluminum mask of 40:1.

Future development plans for the Oxford Cobra ICP include the establishment of a robust silicon carbide process, using an SF6-based chemistry along with additives for sidewall passivation. With the growing importance of SiC based devices among the user community, this will be a nice addition to our increasing etch repertoire.

For further information on these developments, please contact Vince Genova of the CNF Research Staff at Genova@cnf.cornell.edu.





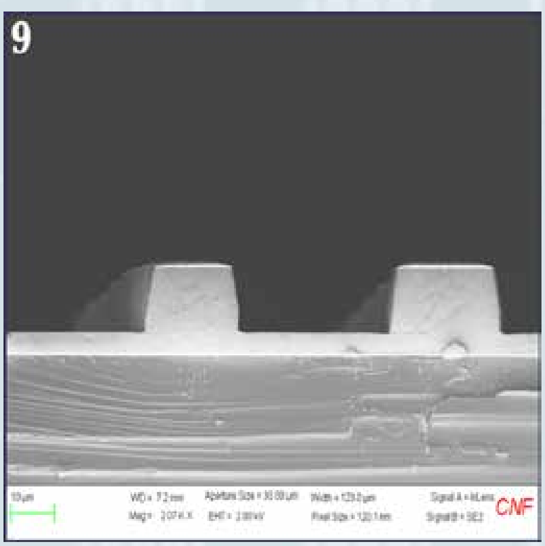
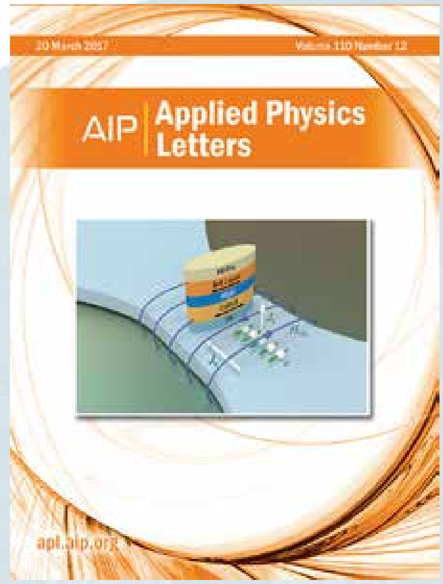


Figure 7: HBr/Ar-Low Freq. 4 µm gap.
Figure 8: HBr/Ar-Low Freq. 800 nm gap.
Figure 9: UNCD etch using O_2/SF_6/Ar.

Duffield Hall! Top: Artist rendering (artist unknown). Middle: First floor plan. Bottom: Duffield Hall today, in the moonlight (Harrington Photography).

Hi, Melanie; I wanted to share two journal covers in the last few months.



1. Cover of Nano Letters, October 2016

URL: http://pubs.acs.org/toc/nalefd/16/10

This illustration shows an artistic rendering of a three-terminal device consisting of a magnetic tunnel junction atop a conducting channel of material with large spin Hall effect. Charge current within the spin Hall channel creates an orthogonal spin current, exerting a torque on the adjacent magnetic layer (red). Micromagnetic simulations highlight the highly nonuniform local magnetic structure during the switching of the magnetic layer, which is favorably influenced by the Oersted field generated by the current in the spin Hall channel.

2. Cover of APL, March 20th 2017 issue

URL: http://aip.scitation.org/toc/apl/110/12?expanded=110

We report on comprehensive elucidation of the switching dynamics in 3-terminal magnetic tunnel junctions (3T-MTJs) obtained through fast-pulse measurements in a variety of material stacks and detailed micromagnetic simulations. We demonstrate that the interaction between the self-generated Oersted field in 3T-MTJs and the micromagnetics of the free layer can lead to reliable sub-nanosecond reversal, in contrast to conventional spin transfer torque (STT) switching. These results, along with reliable cryogenic operation, establish the in-plane 3T-MTJ as an attractive memory element due to its high magnetoresistance read signal, low impedance write path, and fast, reliable switching.

Regards, Sriharsha V. Aradhya, Ph.D. | Postdoctoral Researcher | Cornell University

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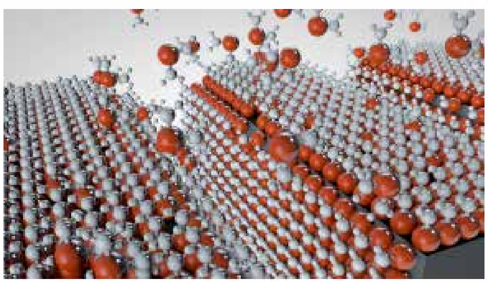


Prof. Engstrom serves as a Guest Editor for a Special Topic in The Journal of Chemical Physics

Jim Engstrom recently served as a Guest Editor for a Special Topic in The Journal of Chemical Physics, entitled: "Atomic and Molecular Layer Processing: Deposition, Pattering and Etching," and over 20 research groups world-wide contributed to this special issue. Thin film processing technologies that promise atomic and molecular scale control have received increasing interest in the past several years as traditional methods for fabrication begin to reach their fundamental limits. It is anticipated that research in this topical area will impact a variety of technologies including optoelectronics, photovoltaics, displays and micro-electromechanical systems, and possibly areas such as batteries, fuel cells and supercapacitors.

http://dx.doi.org/10.1063/1.4975141

A poster entitled "Black Phosphorus MOSFETs and CMOS Integration" and coauthored by K. Xiong, L. Li, J. C. M. Hwang, A. Goritz, M. Wietstruck, and M. Kaynak was presented at the 4th Muju International Winter School Series (MIWS2-2017), Muju, Korea, February 5-9, 2017 — and won Best Poster!

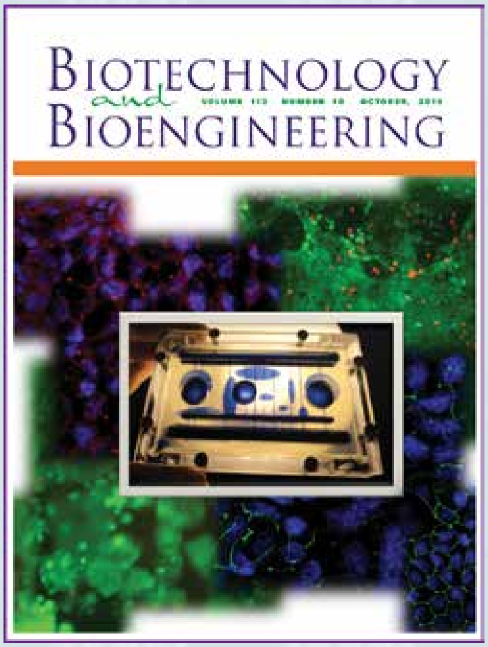
By the way, you might be interest in knowing that, as a heavy user of CNF, I have been named the Recipient of this year's "Pioneer Award in Nanotechnology" by IEEE Nanotechnology Council. Thanks, CNF.

http://sites.ieee.org/nanotech/2016-awards-ceremony/

Sincerely, Shawn-Yu Lin

WASHINGTON—The Optical Society (OSA) is pleased to name the 2017 recipients of its prestigious technology awards and medals. The winners include: Martijn de Sterke, Esther Hoffman Beller Medal; Miles J. Padgett, Max Born Award; Paras Prasad, Michael S. Feld Biophotonics Award; Yeshaiahu Fainman, Joseph Fraunhofer Award/Robert M. Burley Prize; Larry Coldren, Nick Holonyak Jr. Award; J. Christopher Dainty, Robert E. Hopkins Leadership Award; Jumpei Tsujiuchi, Emmett N. Leith Medal; Roberto Merlin, Ellis R. Lippincott Award; Dirk Englund, Adolph Lomb Medal; Ming Wu, C. E. K. Mees Medal; Shaul Mukamel, William F. Meggers Award; John Canning, David Richardson Medal; Ken Nakayama, Edgar D. Tillyer Award; Adolf Giesen, Charles Hard Townes Award; Michal Lipson, R. W. Wood Prize (Photo provided by University Photography).

http://www.osa.org/en-us/about_osa/newsroom/news_releases/2017/the_optical_society_presents_15_prestigious_awards/



Shuler CNF Device Cover

Paula Miller from Michael Shuler's group used the versalaser to cut the gaskets for the device featured on the cover of Biotechnology and Bioengineering, volume 113, number 10, October 2016. (The holder was machined over in Clark Hall).

http://onlinelibrary.wiley.com/doi/10.1002/bit.v113.10/issuetoc

Hello Melanie,

For the CNF Community news — I have graduated with a Bachelor's in Science from CALS with distinction in research based on an honors thesis written describing work that I did with CNF and CHESS (Cornell High Energy Synchrotron Source). I will be starting graduate work in Chemistry at Princeton this fall, an opportunity available to me because of my research.

Best, Gabrielle Illava

KennedyLabs
Material Matters

Kennedy Labs got a new grant from NSERC (Canadian National Science and Engineering Research Council of Canada) for ALD metal and graphene research work. Also, we will be speaking at the RF and Microwave Microelectronic Packaging Conference in Paris in April. Our recent graphene experiments at CNF will be featured in part of my presentation.

Best Regards, Brian Kennedy

CNF moved into its new home in 2003 and the Duffield Hall Grand Opening was in 2004. Four hundred friends helped us celebrate! Photograph of our front lobby, 250 Duffield Hall, by Don Tennant.

Schlom Elected to National Academy of Engineering

Darrell Schlom / Provided.

By Syl Kacapyr
Cornell Chronicle
February 14, 2017

Darrell Schlom, the Herbert Fisk Johnson Professor of Industrial Chemistry in the Department of Materials Science and Engineering at Cornell, has been elected a member of the National Academy of Engineering (NAE).

Election to the NAE is among the highest professional distinctions accorded to an engineer. Membership honors those who have made outstanding contributions to "engineering research, practice or education, including, where appropriate, significant contributions to the engineering literature," as well as to "the pioneering of new and developing fields of technology," according to the academy.

Schlom has dedicated much of his career to discovering new materials that possess properties of great value to the electronics industry. In the mid-1990s he and his senior thesis student were the first in the world to suggest the thermodynamic stability of the interface between halfnium oxide and silicon. The replacement of silicon dioxide in all modern silicon-based transistors with halfnium oxide enabled faster and more energy-efficient transistors — a breakthrough that contributed to the materials revolution championed by companies like Intel, IBM and Global Foundries.

More recently, Schlom and his collaborators demonstrated how a new material — a layered combination of strontium, titanium and oxygen — is capable of extending cell phone technology from today's approximately 1 GHz frequency range into the tens of gigahertz frequency range desired for fifth-generation cell phones.

The NAE praises Schlom's "materials-by-design" approach in which he works closely with experts in theory, synthesis and characterization to discover materials with properties superior to those in existence. Schlom and his Cornell collaborators create these new materials with atomic-layer precision by a technique known as molecular-beam epitaxy, which Schlom likens to "atomic spray painting." They also scrutinize the atomic structure of what they have created using powerful microscopes and techniques that can measure the band structure of the materials for direct comparison with theoretical predictions. This powerful, targeted approach to materials discovery has enabled Schlom and collaborators to invent multiple materials with unparalleled performance.

"This recognition by the NAE is really a testament to the talented students, postdocs and collaborators with whom I have had the pleasure of interacting," said Schlom. "Our progress comes from jamming together daily to better understand the intricate inner workings of materials at the atomic level. A critical element of our successful team approach to accelerating materials discovery is direct, honest interactions that cross scientific disciplines, within an atmosphere of respect and trust. The combination of scientific excellence and collegiality makes Cornell ideal for the discovery of atomically engineered materials that will revolutionize electronics."

Today, Schlom is empowering others from around the country to discover new materials through a new national user facility called PARADIM — the Platform for the Accelerated Realization, Analysis and Discovery of Interface Materials. He founded and leads the platform, which is using a $25 million grant from the National Science Foundation to make facilities and expertise from Cornell and its partner institutions available to materials innovators from industry, academia and national labs across the country.

"I couldn't be more pleased to hear the news about Darrell," said Lance Collins, the Joseph Silbert Dean of Engineering. "It was his leadership that led to PARADIM, which will enable the discovery of new materials for applications ranging from energy storage to water purification. And the brilliant discoveries that come out of Darrell's lab help keep Cornell at the forefront of advanced materials worldwide."

After earning his Ph.D. from Stanford University, Schlom worked under two Nobel Prize winners as a postdoc at IBM Research's lab in Zurich, Switzerland. He then joined the faculty at Penn State where he spent 16 years before coming to Cornell in 2008. He's published more than 500 research papers and holds eight patents. Schlom will be inducted into the NAE during a ceremony at its annual meeting in Washington, D.C., on October 8.

Duffield Hall Aerial View, University Photography.

Three Cornell Faculty Elected Fellows of American Physical Society

By Tom Fleischman
Cornell Chronicle
October 20, 2016

Mingming Wu / Provided.

Three professors — representing the departments of Astronomy, Physics, and Biological and Environmental Engineering — have been elected fellows by the American Physical Society (APS). The criterion for election is exceptional contributions to the physics enterprise — including outstanding physics research, important applications of physics, leadership in or service to physics, or significant contributions to physics education. APS fellowships are usually granted to no more than one-half of one percent of all APS members in a given year. There were 248 members elected APS fellows this year, and 102 Cornell professors have been elected since the fellowship was established in 1921.

Rachel Bean, associate professor of astronomy and director of graduate studies, was elected for her contributions to the understanding of dark energy and her cosmological observations to constrain physics beyond the Standard Model of physics. Her group's research focuses on the application of astronomical survey data to improve our understanding of the physical origins of dark energy, dark matter and primordial inflation, and how the observations can distinguish between competing theories. Csaba Csáki, professor of physics, was cited for wide-ranging contributions to theories for physics beyond the Standard Model, from cosmology to electroweak symmetry breaking. His research is in the field of elementary particle theory, aiming to gain understanding of the deepest mysteries of particle physics, including the origin of mass and the origin of different scales in physics.

Mingming Wu, associate professor of biological and environmental engineering, was elected for her research into the biophysical and biochemical drivers that guide bacterial and animal cell migration, and the creation of single-cell analysis tools. Her lab develops microscale and nanoscale technologies for solving contemporary biological, medical and environmental problems.

Nabil Shalabi/ Provided.

Greetings from Canada

Dear Michael and Chris,

Watching the news got me thinking about you folks in Ithaca. .... I am now in Ottawa for the next couple of months figuring out what's next for me, now that I finished my PhD. Microfabrication has heavily been on my mind. The experience at Cornell has had a lasting impact on me and I will most likely pursue a career path that involves micro-fabrication. I am looking at a few options, and Cornell is defiantly on my mind — the truth is, it is the people there ;). I will be in touch as soon as things start moving for me — who knows, maybe soon I'll be bugging you with endless questions and Friday night overtime! Thank you for the great times that passed and hopefully even greater times to come!

By the way, I am now married to the woman in the gold wafer!

Nabil Shalabi

The CNF Cleanroom Today!
Happy 40th Birthday!

The 2017 Cornell NanoScale Facility FIRST LEGO League Jr. Expo was held on Saturday, January 28th!

The Cornell NanoScale Facility (CNF) hosted the 2017 CNF FIRST LEGO League Jr. (FLL Jr.) Expo on Saturday, January 28th in the Duffield Hall atrium. Over twenty teams of kids, ages 6 – 9, presented their work on the Creature Craze FLL Jr. challenge — to the public as well as friendly reviewers. Local organizations offered fun activities for all to enjoy. Many thank you's to the event coordinator, Daniel Woodie.

Fun activities included:

- **Ithaca Sciencenter crafts and stomp rockets**
- **Cornell Herpetology club had various reptiles on display**
- **Cornell Raptor Club was present with activities for kids**
- **Ithaca High School's FIRST Robotics Challenge Team Code Red demonstrated their robot**
- **Local Award-Winning FIRST LEGO League Team performed LEGO robotics demonstrations**

All photographs by Don Tennant

Homer High School Visits the Cornell NanoScale Facility!

What a great day, Melanie-Claire!

Thank you so very much for all of the emails, explanations and time spent on our behalf. You truly made our field trip go very smoothly. Please extend my sincere thanks to Beth for organizing and coordinating the very large number of students I brought. Tom Pennell should know that his discussion should be entitled "learning through stand up comedy" as he was a student favorite for sure. Please also thank Melanie Roberts for her power point discussion and her detailed answers to our questions.

Photographs by Melanie-Claire Mallison

Andrea Katz, Isaiah Gray, Amrita Banerjee and Chris Alpha described, explained, joked and answered questions making our time at CNF a real pleasure. Student feedback was extremely positive and I always feel as though we are given extra special treatment. If, indeed, you give us extra special treatment, then I will return an extra special thank you. Rather, if you make everyone feel extra special (which is probably the case) then you are ALL really, really good at what you do.

Thank you for your dedication, attention to detail and flexibility. I hope you have a wonderful day, Hal.

*Start*Up CNF

CNF loves to help launch new companies and create high tech jobs! We know that the costs associated with moving your processing work to a new fab can be a barrier.

As an incentive for US-based small businesses (<10 employees) — including Small Business Innovation Research (SBIR) Awardees — to explore the use of the Cornell NanoScale Facility, ***Start*UP CNF** provides up to $3,000 of (1:1) matching funds that can be applied towards the first use of the CNF Shared Facility*.

If you want to know more, get in touch!

http://www.cnf.cornell.edu/cnf_foundry_partners.html

**This program is made possible through a grant from the Empire State Development Division of Science, Technology and Innovation.*

As a newly-started SBIR-funded company, we are excited to take part in the StartUp CNF program. StartUp CNF will enable us to transition our device fabrication from i-line to DUV lithography, aided by CNF's expert staff.

Thanks again!
Jonathan Alden
Esper Biosciences

Good evening Melanie-Claire,

As an early start-up, every dollar counts and the CNF matching grant enables UltraMend to further our product development leveraging the CNF's usage-fee model enabling us to spend our money testing prototypes not on upfront capital equipment expenditures.

Regards, John Phillips

Career and Technical Education
Innovative Programs
New Visions Engineering

Dear friends at Cornell University:

On behalf of the 2017 New Visions Engineering Class, we cordially thank you for the outstanding tour of Cornell. From the moment we stepped foot on the campus there was always something amazing sitting in front of us. Whether it was a particle accelerator or a demonstration of the superconductor Meissner effect, the tour was overflowing with all kinds of spectacular displays of science and technology.

As aspiring engineers and soon-to-be college freshmen, we greatly appreciated your showing us what goes on behind the scenes of an internationally renowned university like Cornell. Getting an inside look on the specialized labs and undergraduate research projects was both incredible and extremely insightful; witnessing the Autonomous Systems Lab and all of the robots was especially awesome.

Similarly, the tour of the project teams gave us a greater understanding of what colleges have to offer beyond the classroom. College tours don't often explore the details of clubs and activities, so it was a great experience being able to meet and talk with most of the project team leaders at Cornell.

At the end of the day, we really appreciate everyone for all the effort that was put into making our visit excellent. Between the fascinating tours and engaging activities, it's clear a lot of work was involved and we are truly grateful. The trip was fantastic in many ways and it undoubtedly gave each of a us a better grasp of life as an engineering college student. Again, thank you for all of the generosity that you have shown us.

Photograph provided.

Please express our thanks and this note to all the faculty and students who contributed to our day.

Sincerely,

Benjamin Blacklock, Denise Johnston, David Morrell
and the OAOC Engineering Class of 2017

Cornell NanoScale Facility
250 Duffield Hall
343 Campus Road
Ithaca NY 14853-2700

information@cnf.cornell.edu
http://www.cnf.cornell.edu

CNF NanoMeter Spring 2017
Volume 26 • Issue 1

__The Cornell NanoScale Science & Technology Facility (CNF)__ has been serving the science and engineering community since 1977. CNF is supported by the National Science Foundation, the New York State Office of Science, Technology & Academic Research (NYSTAR), Cornell University, Industry, and our Researchers (Users). To be added to the mailing list or to correct a mailing address, please send your request via email to: information@cnf.cornell.edu. You will also find the NanoMeter in PDF online at: http://www.cnf.cornell.edu