

NanoMeter • Newsletter of the Cornell NanoScale Facility
Fall 2017 • Volume 26, Issue 2



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

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 of this issue is from Chengyu Liu and Vince Genova's research described on pages 21-22.

The photographs in this book were taken by primarily by University Photography, but also by CNF Staff, or provided by the author.

Find all the 2017 CNF Annual Meeting & 40th Anniversary Celebration photos online at http://www.cnf.cornell.edu/cnf_2017am.html

The NanoMeter is formatted by Melanie-Claire Mallison, and is printed on 30% post-consumer content paper using soy-based inks.

Please reduce, reuse, and recycle!

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Welcome to the 2017 Fall Edition of the CNF NanoMeter

Directors' Introduction

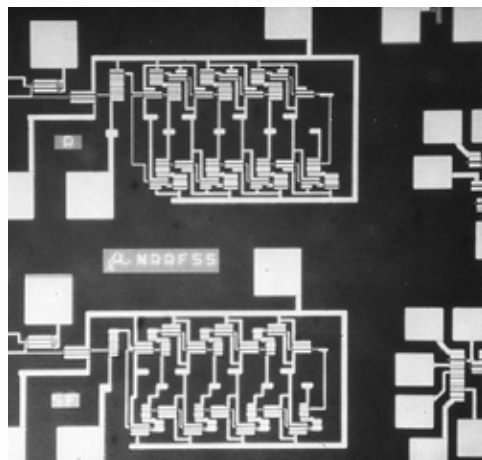
This year the Cornell NanoScale Facility (CNF) is having its 40th anniversary. Since its beginning, CNF has focused on making the smallest structures for both scientific and technological interest. Serving the academic, government and industrial communities as a national facility, it provides the tools and methods of nanoscience. But more importantly as it has done from its foundation CNF provides knowledgeable outstanding staff, there to ensure the best results possible.

In recognition of our fortieth anniversary, we held our annual user's meeting on September 14th — featuring a program of a dozen invited speakers who shared with us new directions and new concepts in nanoscience and technology. Speakers described recent developments in the Internet of things (IoT), AI, nanophotonics, 2D materials and nanobiotechnology. Over 250 attendees listened to the talks and saw over 80 posters presented by numerous user teams.

One of the most compelling stories was of an electronic bracelet made for illiterate women of developing countries who were expecting a child. The bracelet provided advice of the different stages of pregnancy and also incorporated safety features such as a CO₂ sensor to prevent over exposure to CO₂ while cooking over an open fire in their one room home. Stories like this and more told during our meeting are included on our website. As you visit the website, also look for our photo album showing pictures from the last forty years of CNF's history. http://www.cnf.cornell.edu/cnf_2017am.html

In addition to the many poster prizes we presented this year, we also presented two Nellie Whetten Memorial Awards, instead of the typical one, on the occasion of our 40th year. The Whetten award is presented in remembrance of the young woman CNF researcher who worked at CNF for three years and exemplified both research excellence and an uplifting spirit. This year, our two award winners were Chengyu Liu and Melanie Roberts. See pages 8-11 for more!

In addition to our users, it is important to recognize the donations many groups have made to the success of CNF including the equipment vendors who have often enabled CNF to acquire superior enhanced equipment. This year our vendors also enabled a large number of poster prizes. I would like to single out the Knight family for their generous gift of support for the facility in which CNF is housed. From the old sub-micron facility (sub- μ as it was on the roof) to today's much larger user facility, we have benefited from generous support from alumni and other donors who have enabled Cornell to stay at the technology forefront. We are counting on Cornell alumni support going forward as we work to continue our excellence in future years.



NNF National Nanofabrication Facility at Cornell



Craighead becomes director of NNF

Harold G. Craighead of Bell Communications Research, former director of the Cornell Nanofabrication Facility (CNF) in January, Professor Craighead has a joint appointment to the Schools of Applied and Engineering Physics and Electrical Engineering.

Craighead intends to maintain the facility's lead in technology advancement. "The NNF can play a leadership role in applying the techniques of nanofabrication to photonic devices and optoelectronic circuits, growth areas of global importance," Craighead has said.

The appointment was announced by Joseph Ruderman, Cornell vice president for research and advanced studies, who said that Craighead will be "very effective in collaborating with a wide range of university, industry, and government users."

Craighead holds B.S. and M.S. degrees from the University of Maryland and a Ph.D. from Cornell.

We can play a leadership role in applying the techniques of microfabrication to photonic devices and optoelectronic circuits, growth areas of global importance.



Harold G. Craighead
 Since, and work in the areas of high energy electron-beam lithography, noncontact semiconductor processing, and electron microscopy.

Not another newsletter!

By Greg Gullis, Deputy Director NNF

One of the great promises held by the electronic industry is the ever growing heritage of paper. Unfortunately the paper heritage has eroded substantially and has been supplemented with electronic and weblogs. In light of this dismal state, why should NNF provide yet another newsletter to add to the collection of good intentions on your desk? Because we had to be it. Perhaps we had to be it if someone made a commitment to us.

ing publishing it and we'd all get it. The editorial staff's progress of the NNF, formerly known under the acronym PROGRESS, speedily produced a computer printed PROGRESS forum. The last issue was produced by Professor Peter Swartz in the Spring of 1997. Since that time I have received a number of questions from users wondering as to what has happened to the forum. Before I give all that someone will have noticed.

Since, back by popular demand in the 1990s, we go with our own name in a sort of identity for the newsletter. One which we hope will be more readily identified with the

facility than in the past. The newsletter will be more relevant to users than, research announcements, upcoming events, faculty activities, and the like. We do not intend to publish in-depth technical articles — there are reports and journals enough for that. We do not need your feedback. The only reason for this newsletter is to communicate to you what is taking place at NNF and Cornell. Without your feedback we will not know if our communication is successful. Give us a call or send us a note (typical or electronic) and let us know what you'd like to see in the newsletter.

CNF Cornell Nanofabrication Facility





A planning workshop was also organized for the day following the annual user meeting to help CNF leadership consider the tools and skills needs for the next decade of research. This thinking is also influenced by the merger of portions of the Nanobiotechnology Center (NBTC) into CNF. A pioneer in the combination of biology with nanotechnology, the NBTC will provide us with new capabilities and directions. Once we receive the final reports from our three workshop groups, we will begin the process of planning for future directions with our Executive Committee.

It has been over a year since I became CNF director and it has been exciting as we put in place plans for the future of CNF. I have particularly enjoyed working with the staff and the leadership at CNF.

I remain very upbeat about the future of nanoscience. One of CNF's goals is to serve the needs of researchers in the fields of nanoscale science, engineering and technology. Along with academics, we work closely with startup companies on topics ranging from improved DNA sequencing to better metrology for the semiconductor industry. We also support the activities of larger companies by providing tools and capabilities they cannot easily find in house or by providing experience that will enable process or technique selection for their future activities.

Two additional items you might appreciate include our celebration of National Nanoday (October 9, 10/9) this year, where our Cornell mascot (Touchdown the Bear) raced a CNF researcher in a clean room suit over a distance of 100,000,000,000 nm. In addition, a member of the Engineering Communications staff visited CNF and afterwards wrote an article entitled "What goes on in there? A visit to Cornell's NanoScale Science and Technology Facility." If you ever tried to explain your impressions of CNF to a non-user, this nicely written article gives a view by a non-expert from the inside. (See pages 18-19, and 25.)



New Equipment and Capabilities

The CNF continues to upgrade its capabilities. New tools have been acquired and new processes developed over the past year and represent a significant investment in renewing and enhancing lab capabilities. Please see the CNF website for the names of the staff members to contact for further information or training.

Our plasma etch engineer, working with the CNF Fellows, has developed new processes for: etching Diamond-Like-Carbon and nanocrystalline diamond; HBr etch of silicon and SOI with reduced lag; High and low rate GaAs etching; deep germanium etching; and several modified metal etches (Al, Cr, Ti).

We introduced a block copolymer process into the lab to allow users to access quasi-periodic nanostructures without the need for lithography. And new materials and processes have been introduced using nanoimprint lithography that improve the pattern transfer in etch and liftoff in conjunction with our Nanonex imprint tool.

The merger with NBTC has built on our expertise in synthesis and ALD coating of nanoparticles by adding two instruments, the Malvern Zetasizer and Nanosight, for nanoparticle characterization to the portfolio.

Through a cooperative effort of the research division and the ECE department at Cornell, we are pleased to announce that we have ordered a new scandium doped-AlN piezoelectric material deposition system. We expect to receive this instrument in early 2018! This will allow us to be a leading lab in research related to RF filters and piezo-MEMS.



Educational Outreach

The CNF participates in numerous educational outreach activities — over 118 distinct visits and events in the past year — hosting visits, tours and events for approximately 3,500 participants; from prospective graduate students and new faculty members, to visiting dignitaries and corporate executives, from large public events and to smaller visiting groups. We again hosted signature outreach events that included the 4-H Career Explorations and the FIRST® LEGO® League Jr Expo. We enjoy meeting and working with middle and high school students — introducing them to the nano-world we live in. Contact Melanie-Claire Mallison with your visit request (mallison@cnf.cornell.edu).

Twice a year, we offer our short course, “Technology & Characterization at the Nanoscale” (CNF TCN), open to participants from academia, industry, and government. It includes lectures and demonstrations, and also hands-on lab activities in the cleanroom. The next short course will be offered in January 2018. More information is on page 30.

We are grateful to the National Science Foundation for its continued funding for our Research Experience for Undergraduates (REU) Programs, as we continue to successfully operate both a national and an international version of the ten-week summer program. We also seek corporate funds to augment both programs. Please contact Dr. Lynn Rathbun, our REU Programs Manager, to discuss corporate sponsorship (rathbun@cnf.comell.edu).

Let me close by saying that as always, we enjoyed having an excellent group of REU students this last summer. Outreach — that is, sharing our excitement about nanoscience with our broader communities — is something we really enjoy doing. This group of REU students engaged in projects involving use of CNF’s advanced tools working on activities that pushed back the frontiers of nanoscience. The summer ended with convocation in Atlanta, Georgia, the home of the NNCI coordinating site. We have also put out a new edition of Nanooze, our educational publication aimed at K-12 students and we are updating the Nanooze display located at Disney’s EPCOT center.

All in all, it has been an interesting year.

Cornell is a founding member of the National Nanotechnology Coordinated Infrastructure (NNCI), a network focused on nanoscience and nanotechnology. NNCI has developed into a strong national partnership between 16 centers located around the country.

We welcome inquiries from all researchers about CNF’s capabilities and the NNCI network, especially those with no previous experience in nanofabrication, since the outstanding staff members of the CNF are highly skilled at teaching new users.

And as always, we welcome your comments about CNF and its operations, as well as suggestions for improvement.

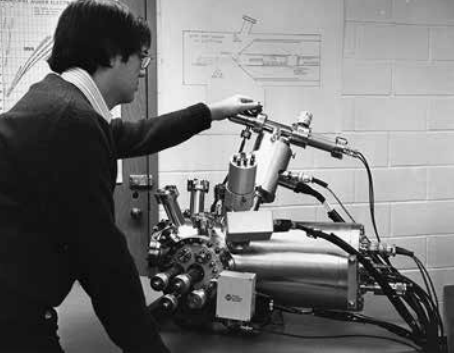
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University Photography

Chris Ober and Don Tennant



Cornell NanoScale Facility Celebrates Forty Years of Nanotech, Focuses on Future

*By Syl Kacapyr
September 7, 2017
Cornell Chronicle*



The Cornell NanoScale Facility (CNF) is celebrating its 40-year anniversary Thursday, Sept. 14, with a full day of presentations and panel discussions that will both reflect on its contributions to nanotechnology and focus on its future.

When it opened in 1977 as the National Research and Resource Facility for Submicron Structures, it was the only facility of its kind, welcoming scientists and engineers across the country to conduct research on a scale approximately 75 times smaller than the width of a human hair. It operated out of Phillips Hall and contained about \$4 million in research equipment. Today, CNF is part of a larger national network of facilities and conducts research on the nanometer scale. With about \$75 million in equipment, the Duffield Hall facility operates 24/7, serving about 650 users a year who conduct research in the fields of biology, electronics, materials science, optics and physics.



One aspect of the facility that hasn't changed in forty years is its expert staff and service-oriented culture, according to Christopher Ober, CNF director. "A lot of other places bring you in and say, 'These are the instructions, don't break the equipment,'" Ober said. "Our staff invests the time in teaching people how to design processes."

Lynn Rathbun has helped to build that culture of service from the beginning. Now CNF's laboratory manager, Rathbun is the lone active staff member from the days when the facility was billed as a place for submicron experimentation. "Originally, CNF was envisaged as primarily a research facility, with equipment and process support provided by graduate students," said Rathbun. "It soon became apparent that professional staff were a necessity. Now, the experienced staff of CNF are, in fact, its most valuable and distinguishing characteristic."



Said Donald Tennant, CNF director of operations: "This is a completely agnostic kind of organization that specializes in bringing in people who have never been here before and getting them up to speed rapidly." He said CNF has remained a top destination for nanotechnology research because of how it has applied its capabilities to multiple areas of research, not just electronics.



CNF has increased its intellectual footprint and facilitated breakthroughs in micro- and molecular electronics. It has also helped lead the fields of magnetic storage and nanobiotechnology, and studies in energy-related systems like batteries and carbon nanotubes. To understand the facility's impact on science, Tennant said one need look no further than its research output. About 100 patents and patent applications are rooted in CNF research each year, as well as about 500 publications, many in top-tier academic journals. Tennant estimates roughly \$40 million to \$60 million in annual research funding is obtained by facility users.



"Also, look at research that has been translated into real companies," said Ober. "Just in recent times: microelectromechanical company Kionix, laser-technology company Binoptics — which was sold to MACOM — and Pacific Biosciences, which is a half-billion-dollar biotech company." But CNF's 40th anniversary isn't just about looking back. People from academia, industry and government will be asked to participate in workshops to help predict the future of nanotechnology research.

"That will help us think about where CNF should go, what unique strengths we can bring to nanoscience, and what kind of facilities and capabilities need

to be created to realize this," said Tennant, adding the information will be compiled into a document that will help guide future CNF decisions.

"You would think after 40 years we'd have it all down pat," Ober said, "but in fact there's just tremendous opportunities to try new things, and there's constantly new challenges."

One of those challenges is purchasing new equipment. CNF was founded and receives most of its funding from the National Science Foundation, but its funding model is changing as competing facilities emerge. Ober says CNF increasingly relies on the generosity of alumni donors with a passion for advancing nanotechnology and keeping Cornell at the forefront of the field. That funding also benefits students, according to Ober. About 320 Cornell graduate students use the facility annually, and dozens of them will showcase their research during a poster session at the anniversary event.

Contact any or all of the three if you want to be part of the next breakthrough in nanotechnology! Director@cnf.cornell.edu, tennant@cnf.cornell.edu, or rathbun@cnf.cornell.edu.



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2017 CNF Whetten Memorial Award Winner: Chengyu Liu

Chengyu Liu is currently a graduate student in the school of Applied & Engineering Physics (AEP) at Cornell University, and is one of 2017's co-recipients of the CNF Nellie Yeh-Poh Lin Whetten Award (together with Melanie Roberts). The Whetten Award recognizes an outstanding female graduate student at CNF who shows spirit and commitment to professional excellence, as well as professional and personal courtesy.



In her spare time, Chengyu likes to play the music and badminton. She will represent Cornell to compete in the Northeast Collegiate Championship in late October.

Chengyu received her bachelor's degree in Electronics from Peking University in Beijing, China in 2013, where she worked in Silicon Photonics and Microsystems Lab for almost two years. Her project was to design and simulate a plasmonic waveguide filter based on side coupled cavities with a unique transmission. In the summer of 2012, she did a research intern in Next Generation Networking Systems Laboratory in the University of California, Davis, to design a high electron mobility transistor on InP/Si platform. Those research experiences have raised her research interests on integrated photonics and electronics devices, but her work only stayed at the design stage. She decided to not only design those devices, but actually make them by her own in graduate school.

After joining Cornell's Ph.D. program in AEP, she joined Professor Jin Suntivich's research group in MSE in April 2014. The research group aims to design and understand materials for energy generation, storage, and conversion. Chengyu's main research interest is to utilize nanophotonic structures or devices to perform strong light-chemistry interaction and enable *in situ* spectroscopy on chip. Understanding surface chemistry is central to a lot of applications in catalysis, corrosion and sensing. Yet, people know little about the chemical species occurring at the solid-liquid interfaces. The challenge is to observe those trace amounts of chemicals at the interfaces in a realistic environment. Suntivich Group has laid the groundwork for a chemical sensor on a chip to analyze samples in the lab and potentially spectroscopically interrogate chemical structures at the interface.

Chengyu's first project is to develop a fabrication process for low-loss titanium dioxide (TiO_2) waveguides and ring resonators. TiO_2 is an attractive material for future integrated optical devices because of its wide, indirect bandgap (3.1eV), high refractive index (>2.2) and negative thermos-optic coefficient. Creating low-loss TiO_2 waveguides and high quality-factor resonators are

critical to enable TiO_2 as a promising candidate for integrated photonic circuits.

She and her colleagues have developed a dielectric lift-off process to avoid etching-related sidewall roughness to generate a smooth waveguide surface. The process flow is demonstrated in Figure 1.

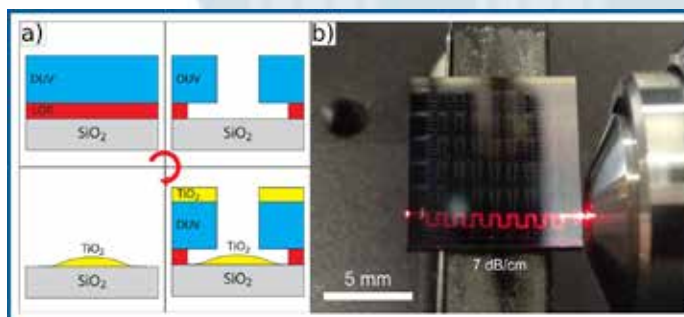


Figure 1: a) Fabrication process flow for the dielectric lift-off method. b) Light guiding in a single-mode TiO_2 channel waveguide.

A bi-layer resist stack (lift-off resist/deep-ultraviolet resist) is used here for DUV lithography to create openings. Next, TiO_2 is deposited by reactive sputtering into the openings. Finally, TiO_2 channel waveguides are formed by lifting-off the resist. This approach achieves single-mode waveguide losses as low as 7.5 dB/cm at 633 nm wavelength and 1.2 dB/cm at 1550 nm wavelength, which currently holds the best record performance for TiO_2 waveguides. The yielded TiO_2 micro-ring resonator has a quality factor as high as $1.5 \cdot 10^5$ around 1550 nm.

After establishing TiO_2 as a material candidate for integrated optical devices, she and her colleague have expanded this platform for functional optics. By utilizing the evanescent field around the TiO_2 lift-off waveguide, she has demonstrated a Raman detection of difference chemical environments through the waveguide. A schematic representation of this waveguide-based evanescent Raman scattering device is shown in Figure 2a. The principle of this evanescent Raman spectroscopy is to guide both pump and Stokes signals within the same waveguide. A visible light is pumped into the waveguide; pump light excites the analyzed molecules on the waveguide surface via evanescent field. The generated Stokes signal will be coupled back into the waveguide and propagate within the waveguide and eventually collected at the waveguide output for analysis. Several common organic solvents serve as liquid cladding to demonstrate the functionality of this device, where the Raman spectra change systematically indicating different chemical vibrations near 300 cm^{-1} (Figure 2b). This preliminary work shows the potential of a fully integrated on-chip Raman sensors for medical diagnostic, environmental quality monitoring applications. Now she is working on optimizing the device performance for trace amount detection and *in situ* spectroscopy.

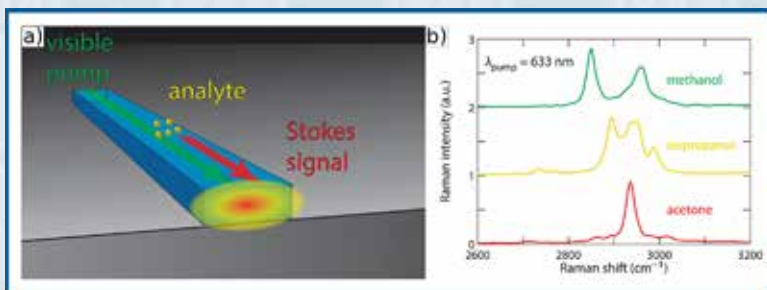


Figure 2: a) A waveguide-based evanescent Raman scattering device, showing the waveguide, analyte, and the guided pump and Stokes beams. b) The comparison of Raman spectra between different organic solvents.

Besides her research projects, she has served as a CNF Fellow since 2015. Her project is to develop and optimize the recipes for nanoimprint technique following in the footsteps of former CNF Fellows Carol Newby and Kathryn McGill. Nanoimprint lithography is an emerging technology for high throughput fabrication with sub-10 nm resolution. It has been a strategic method on ITRS roadmap for the 45 nm node and below and can benefit not only electronics but also many other applications, for example nanophotonics, biotechnology and microelectromechanical systems. She has helped to evaluate two new thermal imprint resists from Microresist Technology on Nanonex NX-2500 imprint tool and demonstrated effective pattern transfer into both silicon and silicon based dielectrics using advanced ICP based reactive ion etching, which was featured in the Spring 2017 edition of NanoMeter. Also she has continued the process development on the new UV imprint resist and the result summary will be presented in the latest Nanometer.

Chengyu would like to express her sincere thanks to all CNF staff for their advice and encouragement through her journey from a fabrication newbie to an experienced user. She also would like to thank her advisor Professor Jin Sunvitch for giving her the opportunity to work in this fantastic facility both as a user and a CNF Fellow. She will continue her exploration in the nanoscale world and keep contributing to CNF community.



2017 CNF Whetten Memorial Award Winner: Melanie Roberts

Melanie Roberts is a graduate student in Mechanical Engineering, and is one of the 2017 co-recipients of the CNF Nellie Yeh-Poh Lin Whetten Memorial Award (along with Chengyu Liu, pictured below). This award recognizes young women whose work and professional lives exemplify Nellie's commitment to scientific excellence, interdisciplinary collaboration, professional and personal courtesy, and exuberance for life.

Melanie received her bachelor's degree in Mechanical and Biomedical Engineering from Rensselaer Polytechnic Institute (Troy, NY) in 2014. She joined the Ph.D. program at Cornell that fall in the lab of Prof. Christopher J. Hernandez. The Hernandez Research Group (in the Sibley School of Mechanical and Aerospace Engineering and the Meinig School of Biomedical Engineering) focuses on the mechanical properties of biological materials and the response of living organisms to mechanical stimuli.

Melanie's research examines the response of bacteria to mechanical loading. Bacteria exist in mechanically hostile environments and must resist a wide range of mechanical forces in order to survive and grow. Changes to bacterial mechanical properties can influence bacteria viability and ultimately virulence.

Silica microfluidic devices are fabricated for mechanical testing of live bacteria. Individual bacteria are flowed into the device and trapped within tapered channels. The distance at which bacteria become trapped depends on whole cell stiffness: less stiff cells are able to travel further into the channels (Figure 1). This microfluidic platform can thus be used to profile biomechanical properties of bacteria without significant sample preparation and does not require fixation or labelling.

The fused silica channels are fabricated with deep UV lithography (250 nm feature size) and plasma etching before sealing with a silica cover wafer via fusion bonding. The design applies twelve different pressure magnitudes to establish biomechanical profiles for tested bacterial strains (Fig. 2) (Sun, et al. 2014). Differences in fluid pressure across trapped cells generates mechanical stress along the cell wall. A theoretical mechanical model derived from fundamental elasticity can be used to determine the stress distribution along individual, trapped bacteria (Roberts, et al. 2016). This analysis suggests that trapped bacteria experience predominately tensile stresses where the maximum stress is experienced at the downstream point of contact with the channel walls.



Melanie Roberts, provided

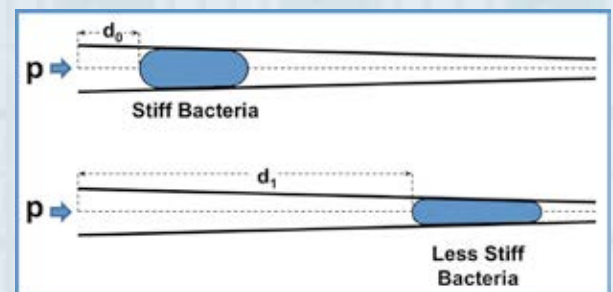
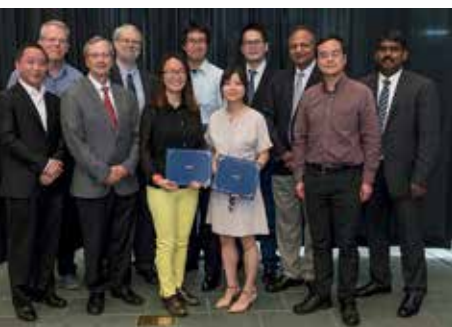
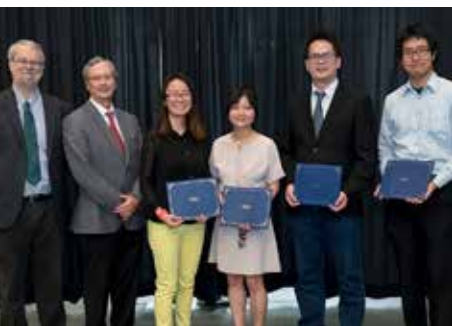
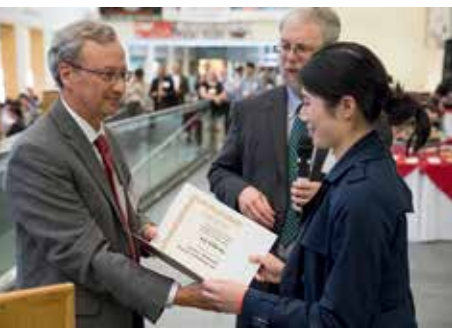


Figure 1: Bacteria under fluid pressure (p) are flowed into tapered channels. The distance travelled by the cell depends on cell stiffness. More compliant cells travel farther into the channels (d_1) than stiffer cells (d_0). Observing deformation of the cell under two different applied pressures can be used to determine mechanical properties of the trapped bacteria.

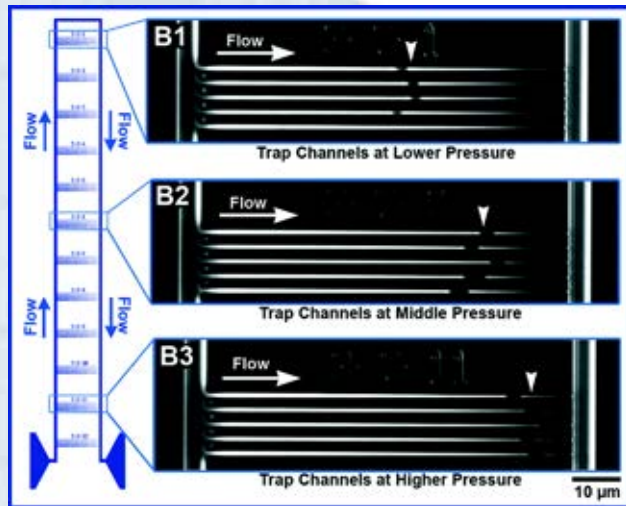


Figure 2: A single loading device. Twelve different applied pressures are implemented by the microfluidic device, seen as twelve sets of channels within the device. The applied pressure across trapped cells is greatest closest to the device inlet. Bacteria trapped within the tapered channel appear dark using phase contrast microscopy (white arrow heads). Note that bacteria travel farther into the tapered channels when under greater applied pressures. (Figure from Sun et al. 2014)

A non-uniform stress distribution along the cell wall enables study of bacterial response to mechanical stimulation. Preliminary work suggests that bacteria under greater non-uniform stress grow at a slower rate, demonstrating reduced cell fitness.

Additional work has looked at the activity of a multi-component protein system in Gram-negative bacteria that spans the inner membrane, periplasm, and outer membrane. These multicomponent protein systems are involved with antibiotic resistance. Preliminary results suggest that mechanical stress may impede multicomponent protein functioning and thus interfere with antibiotic resistance.

Outside of research, Melanie is an avid fan of baseball, and she'll be following the free agent market closely this offseason to see if the Red Sox keep Mitch Moreland. Beyond baseball, she looks forward to her career in biomechanically inspired nanofabrication.

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Photograph provided by Tim Whetten

Nellie Yeh-Poh Lin Whetten; CNF Memorial Award

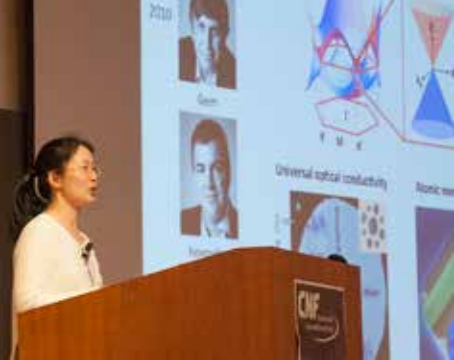
This award is given in fond memory of Nellie Whetten (pictured above) — a CNF staff member from 1984 to 1987 who died on March 24, 1989. This award recognizes outstanding young women in science and engineering whose research was conducted in the CNF, and whose work and professional lives exemplify Nellie's 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**

Patented Biomedical Implant Could Improve Heart Patient Outcome

By Tom Fleischman
August 9, 2017
Cornell Chronicle



Over the course of a year, the average person's heart will beat nearly 40 million times. Stretched over a lifetime, that number often exceeds 2 billion.

That's a lot of wear and tear on the valves, which regulate the one-way flow of blood through the body. Valve failure can cause blood to back up, which can lead to serious and sometimes fatal heart failure.

"If blood flows in a direction that it's not supposed to at any point in the heart cycle, your heart has to pump more to get it moving in the right direction," said Jonathan Butcher, associate professor and associate director of the Nancy E. and Peter C. Meinig School of Biomedical Engineering.

Butcher's research themes involve understanding how the tissue in heart valves functions in normal health, how the valves get diseased, and how to deliver therapies that can keep the valves functioning longer before they need to be replaced. And one of Butcher's latest projects involves an innovative procedure for when they do need replacing.

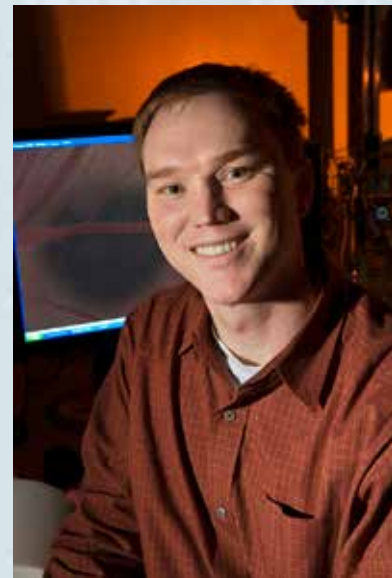
In April, Butcher and Christopher Frenzl '10, M.Eng. '11, were awarded a patent for a biomedical implant for use in fluid shear stress environments, such as the heart. Since that time, Butcher has co-written a grant proposal for funding to take their implant idea further with a preclinical animal trial.

Their invention is a method for making a prosthetic heart valve more suited to the environment into which it's placed. It's both mechanical and biological — a "bio-hybridized" cell-coated prosthetic.

Current replacement heart valves are made either of treated animal tissue (pig, cow) or a combination of plastic and metal. The former is less durable than the latter and is well-suited for people over age 70, who typically are less active than younger people.

The problem with the latter: Since they are not biological materials, Butcher said, circulating blood components will adsorb onto the surfaces. That can cause clots, so the individual must take blood thinners. Lots of them. "And those blood thinners basically eliminate you from military service, from being a policeman, a construction worker, basically any physically risky job. It also forces a lot of lifestyle changes that children and active people do not want," he said.

That leaves younger patients with "basically no good option," Butcher said, but his bio-hybridized approach could help change that. The invention for which he and Frenzl earned a patent involves adding trenchlike niches to the prosthetic and filling them with living cells, which would help regulate normal function within the heart. The niche protects the cells from being swept away by the flow of blood.



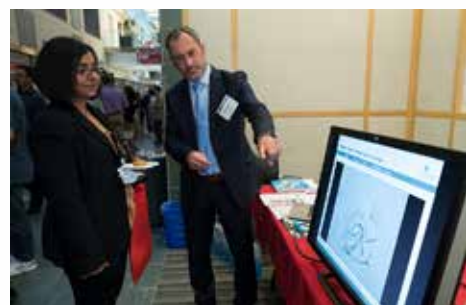
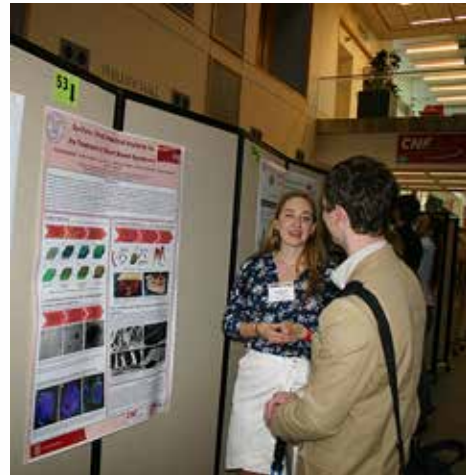
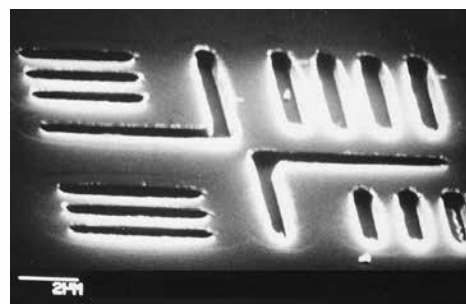
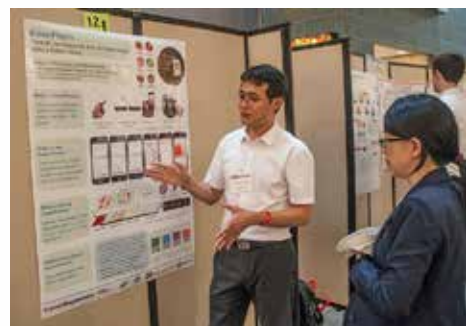
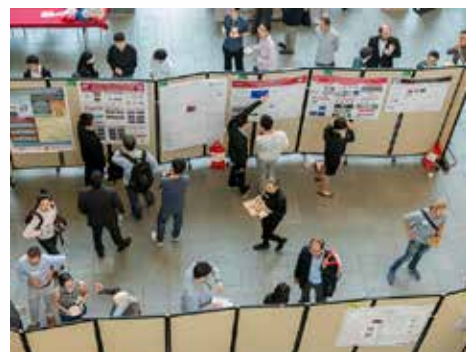
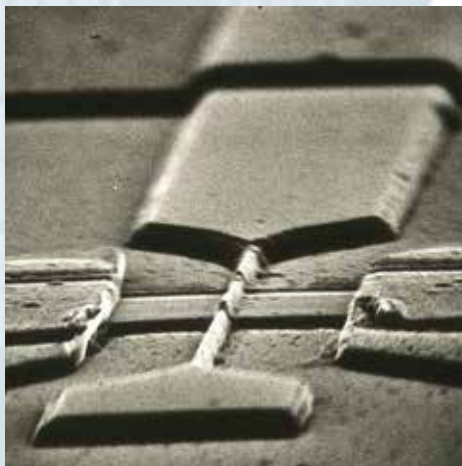
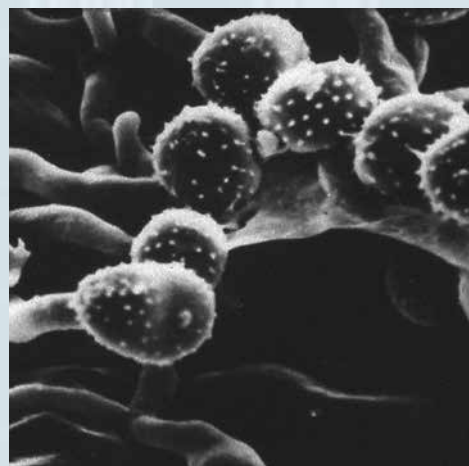
Jonathan Butcher

“You add a living component to the prosthetic, and that living component hopefully naturally regulates coagulation, protein absorption and so on, so that those patients could maybe have far more reduced anti-coagulant drug treatment so that they can have a more normal life,” Butcher said. “You also eliminate those risks of mechanical failure that are incumbent with the bio-prosthetic [animal tissue] valves. You’re trying to get the best of both worlds.”

The grant that Butcher co-wrote with James Antaki, professor of biomedical engineering at Carnegie Mellon University — who will join the Cornell faculty in January 2018 — would help fund preclinical testing aimed at determining whether the bio-hybridization strategy needs to be different for left- and right-side valves. They will also conduct more in-depth study of clotting, as thrombosis is a specialty of Antaki’s. Further study would likely involve testing the bio-hybridized implant in a pig since, as Butcher said, pigs and humans have very similar cardiovascular problems.

“Pigs are affected by cardiac surgery the same way as humans,” he said. “Like humans, they don’t tolerate anesthesia and bypass well and they have to recover in the hospital for days. Whereas sheep — which are a very prominent FDA model for cardiovascular work — come off bypass surgery and are walking around in an hour. That’s a little unrealistic for humans.”

The patented method was described in a 2014 paper in the journal *Biomaterials*. Support for the research came from the National Institutes of Health and the Cornell University Engineering Learning Initiatives. Some of the work was performed at the Cornell NanoScale Science and Technology Facility, which is supported by the National Science Foundation.





Collaboration Employs New Strategies to Study the Spread of Cancer

Cornell Center on the Physics of Cancer Metabolism

About Us

The Cornell Center on the Physics of Cancer Metabolism integrates engineering, advanced imaging, and cancer biology to interrogate the multiscale biophysical mechanisms regulating tumor metabolism and function as well as their consequences on clinical outcome.

Finding new ways to study cancer and how it spreads is the goal of the Center on the Physics of Cancer Metabolism, a new translational research program that taps into expertise at Cornell University and Weill Cornell Medicine, with investigators at MD Anderson Cancer Center and the University of California, San Francisco.

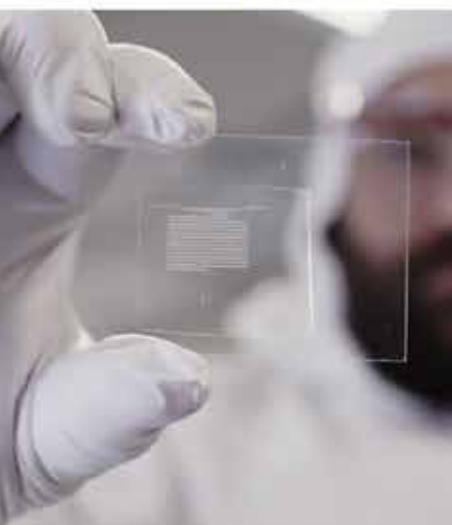
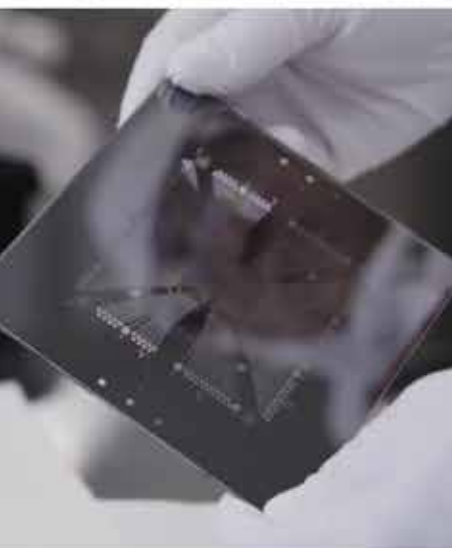
Center Overview

Despite advances in breast cancer treatment, metastatic disease remains incurable and is of particular concern in patients with triple negative breast cancer. Both aberrant metabolic signaling and physical properties of the microenvironment have been independently defined as hallmarks of cancers, and experimental evidence suggests that they may be functionally linked. However, the current lack of physiologically relevant culture models that capture relevant physical details prevents studying the specific mechanisms that link metabolic reprogramming, the physical microenvironment, and clinical outcomes of malignancy. By leveraging capabilities of five different institutions the Cornell Physical Sciences Oncology Center (PSOC) will interrogate the multiscale biological and physical (structural, mechanical, and solute transport) mechanisms regulating tumor metabolism and function, as well as the consequences on tumor development, metastatic progression, and therapy response. The new physical sciences-driven mechanistic insights that will be generated by our PSOC promise to inform a more integrated approach to the prevention, diagnosis, and treatment of breast cancer.

<https://vimeo.com/201165591>

Participating Institutions

- Cornell University (Cornell NanoScale Facility)
- Meyer Cancer Center @ Weill Cornell Medicine
- Memorial Sloan Kettering Cancer Center
- MD Anderson Cancer Center
- University of California San Francisco



First-Ever Visualization of Enhanced Catalytic Activity Reported

By Tom Fleischman
November 1, 2017
Cornell Chronicle

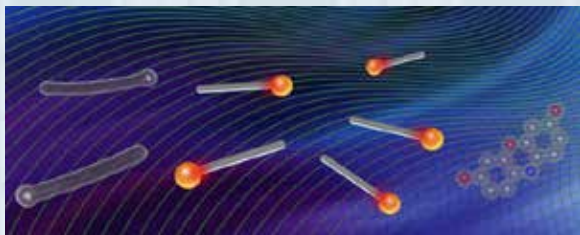


Figure 1: Catalysis imaging. Provided

Single-molecule super-resolution catalysis imaging visualizes the enhanced catalytic activity at the palladium-gold interface in single bimetallic nanoparticles.

Just as two heads are better than one when trying to solve a problem, two metals are better than one when trying to catalyze a chemical reaction.

Compared with their monometallic counterparts, bimetallic nanoparticles often show enhanced catalytic activity at the interface of the two component metals. These nanoparticles are important in heterogeneous catalysis, such as when a mix of precious metals in a car's catalytic converter triggers the reaction of carbon monoxide with oxygen to form carbon dioxide.

Direct measurement of catalytic activity at the bimetallic interface is important for understanding the enhancement mechanism but to date has been hard to quantify.

Peng Chen, the Peter J.W. Debye Professor in the Department of Chemistry and Chemical Biology, has used his expertise in the study of single-molecule catalysis combined with electron microscopy to visualize, for the first time, enhanced bimetallic activity at the metal-metal interface.

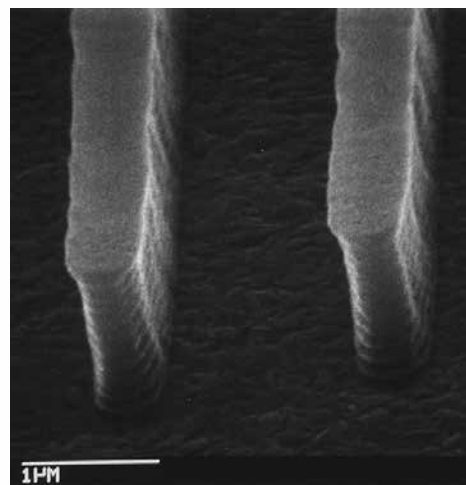
His group's paper, "Bimetallic Effect of Single Nanocatalysts Visualized by Super-Resolution Catalysis Imaging," was published online Nov. 1 in ACS Central Science, a publication of the American Chemical Society. Guanqun Chen, Ph.D. '17, formerly of the Chen Group, is the lead author.

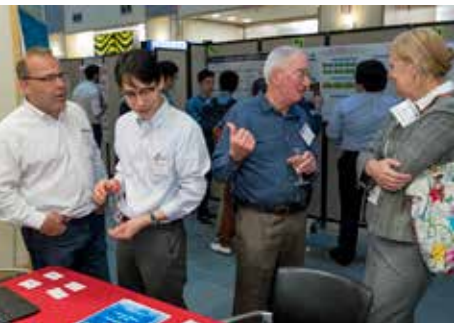
For this work, the group used a bimetallic nanoparticle comprising palladium and gold to catalyze a light-induced disproportionation reaction that cleaves a bond between nitrogen and oxygen. This reaction was chosen because it generates a fluorescent molecule, which can be observed by fluorescence microscopy one molecule at a time.

The single bimetallic particle featured regions that were more bimetallic than others, and was just tens of nanometers wide but several hundred nanometers in length. The length gave the researchers the ability to precisely isolate the bimetallic interfacial region.

Using a single particle assured that any differences between the regions would be a function of the metallic interfaces, not the particles. "It's really important to compare the interfacial region from the non-interfacial region within the same particle," Chen said, "because there can be a lot of differences from particle to particle."

Scanning electron microscopy further structurally identifies the bimetallic interface, where the enhancement was further confirmed when breaking that interface through heating eliminated the enhancement. Theoretical calculations provided further confirmation of and insights into the mechanism of the enhanced catalysis.





“This is experimentally observing something that people knew about but couldn’t see, and now we have a new way of directly seeing it,” Chen said.

This super-resolution catalysis imaging can also scan monometallic sites to find areas of higher catalytic activity, which the group says make the best locations for constructing effective bimetallic compounds.

“We found that the more active site of the first metal is also the better site to put the second metal on, so that the bimetallic site is even more effective for bimetallic enhancement,” Chen said.

The group believes that identifying optimal locations of bimetallic sites could guide future development and design of effective bimetallic nanocatalysts. Their work also demonstrates a methodology of using super-resolution catalysis imaging to study bimetallic nanocatalysts, which can be applied to other bimetallic materials.

Other contributors were: Ningmu Zou, Ph.D. '17, formerly of the Chen group; Bo Chen, a postdoctoral researcher in the group of Nobel laureate Roald Hoffmann, who provided technical advice and facilities for computation; and Eric Choudhary, Ph.D. '14, formerly of the Chen group and now a senior research scientist at 3M.

Support for this work came from the Army Research Office, the Department of Energy and the National Science Foundation. Part of the work was done at the Cornell Center for Materials Research Shared Facilities and the Cornell NanoScale Science and Technology Center, both supported by the NSF.

Where Did Those Electrons Go? Decades-Old Mystery Solved!

By Tom Fleischman
November 2, 2017
Cornell Chronicle

The concept of “valence” — the ability of a particular atom to combine with other atoms by exchanging electrons — is one of the cornerstones of modern chemistry and solid-state physics.

Valence controls crucial properties of molecules and materials, including their bonding, crystal structure, and electronic and magnetic properties.

Four decades ago, a class of materials called “mixed valence” compounds was discovered. Many of these compounds contain elements near the bottom of the periodic table, so-called “rare-earth” elements, whose valence was discovered to vary with changes in temperature in some cases. Materials comprising these elements can display unusual properties, such as exotic superconductivity and unusual magnetism.

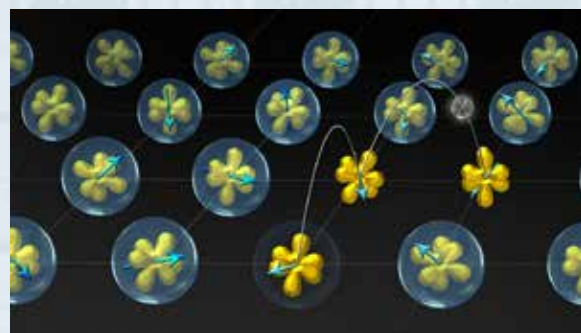


Figure 1: Illustration of ytterbium (Yb) atoms in $YbAl_3$, where electrons transform from localized states (bubbles surrounding the yellow orbitals) to itinerant states (hopping amongst orbitals), as a function of temperature.

But there's been an unsolved mystery associated with mixed valence compounds: When the valence state of an element in these compounds changes with increased temperature, the number of electrons associated with that element decreases, as well. But just where do those electrons go?

Using a combination of state-of-the-art tools, including x-ray measurements at the Cornell High Energy Synchrotron Source (CHESS), a group led by Kyle Shen, professor of physics, and Darrell Schlom, the Herbert Fisk Johnson Professor of Industrial Chemistry in the Department of Materials Science and Engineering, have come up with the answer. Their work is detailed in a paper, "Lifshitz transition from valence fluctuations in YbAl_3 ," published Oct. 11 in Nature Communications. The lead author is Shouvik Chatterjee, Ph.D. '16, formerly of Shen's research group and now a postdoctoral researcher at the University of California, Santa Barbara.

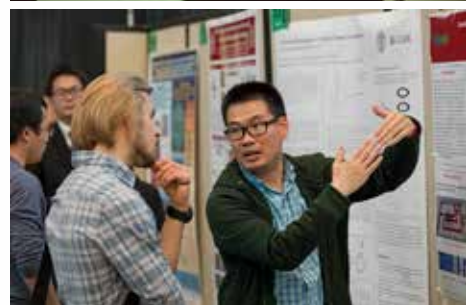
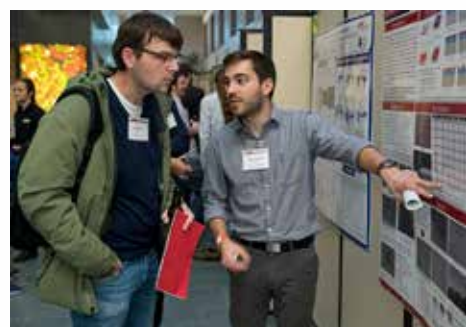
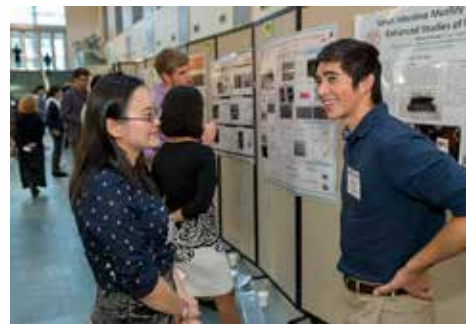
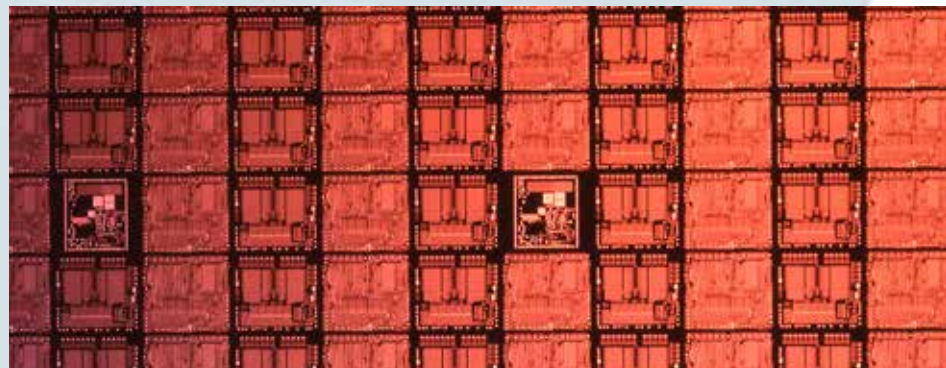
To address this mystery, Chatterjee synthesized thin films of the mixed-valence compound of ytterbium – whose valence changes with temperature – and aluminum, using a process called molecular beam epitaxy, a specialty of the Schlom lab. The group then employed angle-resolved photoemission spectroscopy (ARPES) to investigate the distribution of electrons as a function of temperature to track where the missing electrons went. "Typically for any material, you change the temperature and you measure the number of electrons in a given orbital, and it always stays the same," Shen said. "But people found that in some of these materials, like the particular compound we studied, that number changed, but those missing electrons have to go somewhere."

It turns out that when the compound is heated, the electrons lost from the ytterbium atom form their own "cloud," of sorts, outside of the atom. When the compound is cooled, the electrons return to the ytterbium atoms.

"You can think of it as two glasses that contain some water," Shen said, "and you're pouring back and forth from one to the other, but the total amount of water in both glasses remains fixed." This phenomenon was first proposed by 20th-century Russian physicist Evgeny Lifshitz, but an answer to the electron mystery hadn't been proposed until now. Said Chatterjee: "These findings point toward the importance of valence changes in these material systems. By changing the arrangement of mobile electrons, they can dramatically influence novel physical properties that can emerge." "This places our understanding of these materials on a better footing," Shen added.

Other contributors included Ken Finkelstein, senior staff scientist at CHESS; and doctoral students Jacob Ruf and Haofei Wei of the Shen Group.

This work was supported by grants from the National Science Foundation to CHESS and the Cornell Center for Materials Research. Some of the work was done at the Cornell NanoScale Science and Technology Facility, also supported by the NSF. Other support came from the Gordon and Betty Moore Foundation and the Air Force Office of Scientific Research.





What goes on in there? A visit to Cornell NanoScale Science & Technology Facility

*Written by Chris Dawson
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Often when Hollywood directors want to convey the fact that something very scientific is happening, they will dress the actors in white suits that cover them head to toe—including booties, gloves, and safety glasses. The actors will peer into microscopes, turn some dials, maybe consult a computer printout. As a viewer you are meant to think, “Wow! That must be some VERY impressive science going on in that lab.”

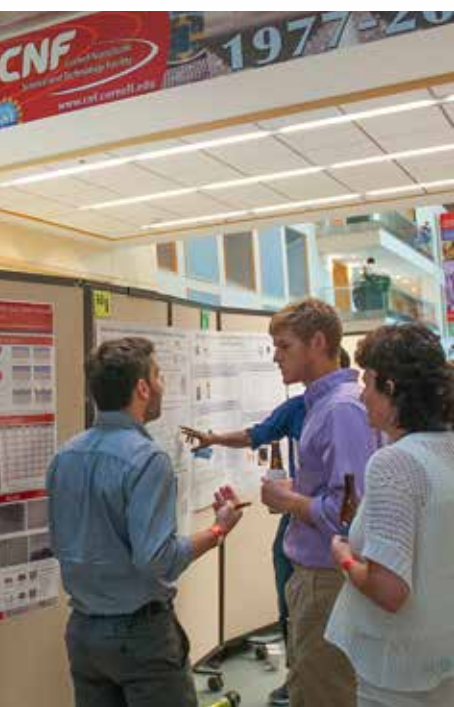
I have seen a lot of movies and television shows in my fifty-plus years. Certainly enough that whenever I walk through the hallways on the first floor of Duffield Hall and peek through the small windows on the doors to each lab, I have the exact reaction those Hollywood directors are aiming for. Sometimes the room behind the door is bathed in a strange yellow light and, sure enough, the person in the room is wearing a white suit with booties, gloves, and safety goggles. “Wow,” I think to myself. “That person is science-ing REALLY HARD. I wonder what goes on in there?”

So imagine how excited I was one recent afternoon to make it through one of those doors and into the Cornell NanoScale Science and Technology Facility (CNF). I did not have to sneak in. No alarms sounded. No warning lights flashed. In fact, I was there with CNF Director Chris Ober and Thin Film Process Engineer Aaron Windsor to get the deluxe tour.

It was clear as we suited up for the tour that both Ober and Windsor really enjoy being in the CNF. They had the air of proud homeowners showing a guest around their dream home. Except instead of built-in bookshelves, a hardwired sound system, and a sauna this dream home has state-of-the-art nanofabrication technology, an expert and dedicated support staff, and forty years of experience at the very edge of nanoscale science and technology.

As we toured the facility and I got to hear about what each of the nanofabrication tools was capable of, I felt like Charlie in Raold Dahl’s Charlie and the Chocolate Factory. Each tool was more capable and more fantastic than the one before. Windsor and Ober knew the equipment inside and out. In most cases they were able to tell me where it had been purchased, how long it had been at Cornell, what it was capable of, and who tended to use it most.

The question of who uses the equipment at the CNF is a bit more complicated than you might assume. The CNF is not, strictly speaking, a Cornell Engineering facility. It was started in 1977 with a \$5 million grant from the National Science Foundation (NSF) and has received support from the NSF ever since. In 2004 the facility found a new home in Duffield Hall, boosted by a \$100 million investment from Cornell. The current configuration has 15,000 square feet of Level 1000 cleanroom. For comparison’s sake, a regular old room — like the one you are probably sitting in right now — has roughly 1000 times more airborne particulates than the cleanroom at the CNF.

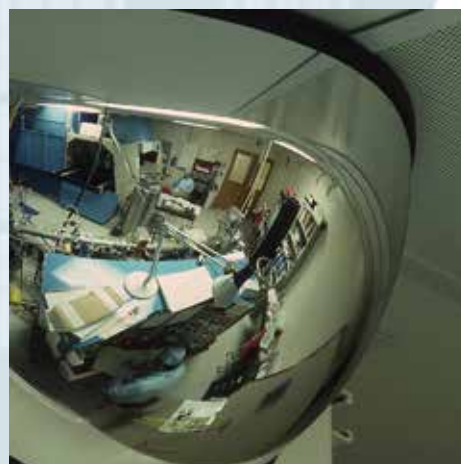
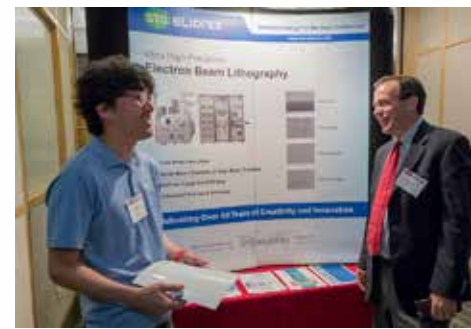
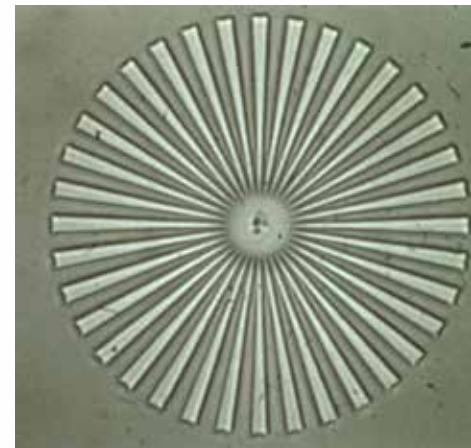
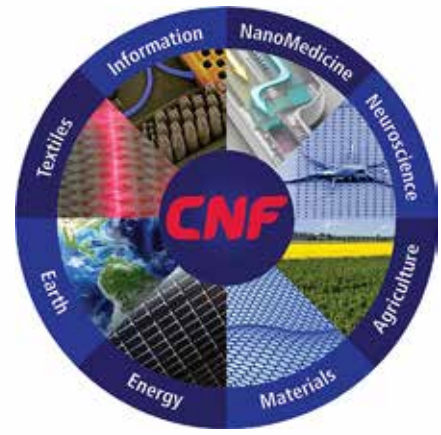


Because the CNF is a general user facility and one of sixteen members of the National Nanotechnology Coordinated Infrastructure (NNCI), its users are not just Cornell researchers. Many are from universities and companies from all over the world. Of the approximately 650 scientists who use the CNF in the course of an average year, about half are from Cornell. Users represent the fields of optics, electronics, physics, chemistry, materials science, MEMS, mechanics, life sciences, bioengineering, and more. The CNF truly is a national scientific treasure.

This year (2017) the CNF will celebrate its 40th anniversary. That's forty years of research in microfluidics, nanomagnetism, and bioelectronics. It is also forty years-worth of electron-beam lithography, photolithography, chemical vapor deposition, electron-beam deposition, and reactive ion etching. Director Chris Ober says that the tools and techniques available are just part of the story at CNF. "The staff are what make this place so special," says Ober. "They know this equipment like the back of their hands and they are willing to work with each user to make sure they have what they need. Our real strength is our people."

Thin Film Process Engineer Aaron Windsor makes Ober's point more concrete. Windsor explained just what a user gets when they sign on for a project at the CNF. "Users get first-class service," says Windsor. "New users work with an in-house User Program Manager to develop a fabrication process plan, receive training, and get 24/7 access and support. We really do aim to please."

As we walked through the 15,000 sq feet and breathed in the remarkably clear air, Ober and Windsor described what each machine was capable of. Some of what they said made total sense and (to be completely honest) some of it was way over my head. By the tour end it was clear that there is indeed some very impressive science going on behind those doors on the first floor of Duffield.





CNF Leverages New Central CULearn Training System

Starting October 16, CNF online training signups are now via the central Cornell CULearn system. CNF Users can sign up for instructor led trainings and can take web-based online courses. Users can also sign up for courses offered by departments other than the CNF.



CULearn is a centralized Learning Management System (LMS) to serve as a one-stop-shop learning hub for the university's many different types of training. The new software provides a whole new look and feel, plus a more robust and user-friendly interface. Other features include:

- CULearn enables learners to begin building their own professional development transcript in a central location.
- Self-motivated learners will be able to register for a wider array of courses and training opportunities in one location.
- CULearn offers enhanced capabilities to sort and find courses — users will be able to filter by topics or sort offerings in a calendar view.
- Pre-built reports and dashboards will enable course administrators and managers to track status of required trainings and report out on completion rates.



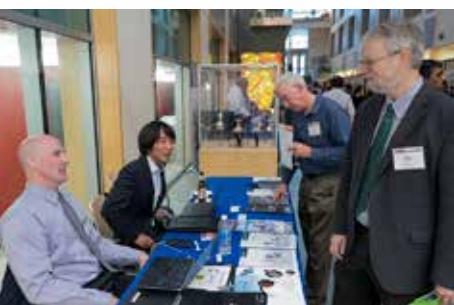
New CNF NoticeBoard Display

CNF Computing has replaced the old flash-based Noticeboard application with a new application. The new application is written in modern HTML5/ Javascript. In addition to using modern standards, the new board positions CNF for the necessary programming to migrate the CNFUsers website to a new website design.

If you discover any bugs in the new noticeboard application, please contact CNF Computing, computing@cnf.cornell.edu.



*Out with the old ...
and in with the new!*



Photocurable Nanoimprint Lithography (P-NIL): 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 have evaluated a new photocurable imprint resist (mr-XNIL26) from Microresist Technology on our Nanonex NX-2500 imprint tool. This single layer resist system has been studied and the removal of residual resist has been optimized with proper plasma etch chemistry and parameters. We have then demonstrated effective pattern transfer into both silicon and silicon nitride using advanced ICP based reactive ion etching.

Experimental

The Nanonex NX-2500 has both thermal imprint (TNIL) and photocurable imprint (PNIL) capabilities. The photocurable imprint module uses 200W narrow band UV lamp. A quartz template was fabricated by sputter depositing a blanket layer of chrome in which 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 chrome using $Cl_2/O_2/Ar$ mixed chemistry in the Trion ICP. This etch produces smooth and perfectly anisotropic sidewall profiles, which are essential for optimum imprint replication. The chrome is used as a hard mask to etch the quartz substrate to a depth slightly less than the mr-XNIL26 resist thickness in the Oxford 80 RIE using CF_4 . The chrome is then removed by immersing the substrate in liquid chrome etchant. The template is coated with FOTS in the MVD system to prevent the adherence of the resist in the imprint process.

The Microresist Technology PNIL resist system evaluated was mr-XNIL26, which is a new fluorine modified UV nanoimprint resist with advanced release properties. We applied the mr-XNIL26-300 nm to a silicon wafer along with Omnicoat as an adhesion promoter, although the adhesion promoter is not necessary. The imprint is performed at room temperature and at a pressure of only 10 psi which is low compared to a thermal imprint process. The UV cure time is 30 seconds. The single layer PNIL process is illustrated in Figure 1.

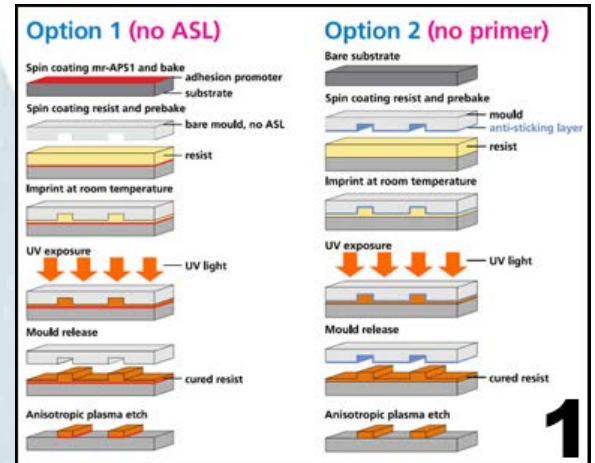


Figure 1: mr-XNIL26 P-NIL process overview.

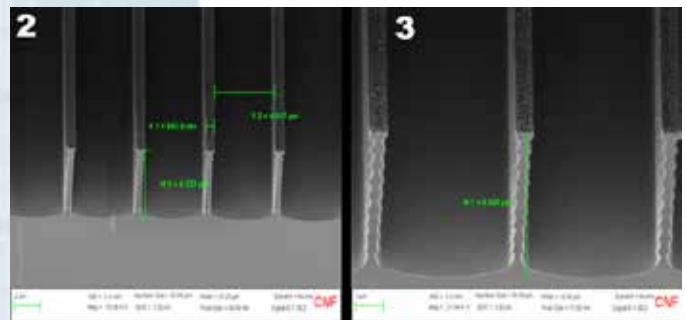


Figure 2: Bosch etch in Plasmatherm SLR-770. Figure 3: Bosch etch in Plasmatherm SLR-770 of 600 nm features to an aspect ratio of 9:1.

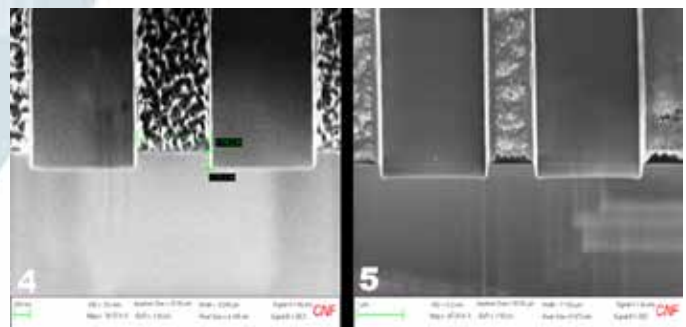


Figure 4: Photonics etch using SF_6/CF_4 in Plasmatherm SLR-770 with selectivity of 3:1 to mr-XNIL26. Figure 5: Oxford Cobra HBr silicon etch with a 4:1 selectivity of silicon to mr-XNIL26.

We used option 1 where Omnicoat was used as an adhesion layer in place of mr-APS1. Residual layer etching is performed in the Oxford Plasmalab 80 using oxygen at low pressure (15 mTorr) and low power (50W) to retain critical dimensions and minimize the loss of resist. The post imprint residual thickness layer is largely dependent on pattern density and feature size. The imprinted Si wafers were etched with the Bosch deep silicon etch and the mixed SF_6/C_4F_8 etch in the Plasmatherm SLR 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. The P-NIL process using mr-XNIL26 resist was also applied to a silicon nitride layer. Pattern transfer into Si_3N_4 was accomplished in the Oxford Plasmalab 100 ICP using CH_2F_2/He chemistry. This dielectric etch is used in the fabrication of oxide and nitride based nanophotonics devices here at CNF.

Results for mr-XNIL26-300nm P-NIL Resist

Figures 2 and 3 illustrate the results of the Bosch deep silicon etch for feature sizes of 600 nm etched to an aspect ratio of 9:1. The selectivity of silicon to the mr-XNIL26 resist is about 40:1, comparable to standard DUV and i-line photoresists.

Figure 4 illustrates the results of silicon etching with SF_6/C_4F_8 chemistry in the Plasmatherm SLR-770. The selectivity of Si to the mr-XNIL26 is 3:1, slightly less than standard DUV and i-line resists.

In Figure 5, we show the results of silicon etching in the Oxford Cobra ICP using HBr. Both the SF_6/C_4F_8 and the HBr etches produce highly anisotropic profiles with smooth sidewalls. Results of pattern transfer into silicon nitride using CH_2F_2/He in the Oxford 100-ICP are shown in Figure 6.



Figure 6: Silicon nitride etch using CH_2F_2/He in Oxford 100 ICP. The CH_2F_2/He chemistry is highly polymerizing and therefore highly selective with respect to imprint and conventional photoresists.

Conclusions

We have evaluated a new photocurable imprint resist (mr-XNIL26) from Microresist Technology on our Nanonex NX-2500 nanoimprint system and have demonstrated successful pattern transfer into silicon and silicon nitride. In addition, this process shows great performance and potential in the fabrication of MEMS and photonics based devices.



2017 OVPR Research Division Service Award Luncheon

On Thursday, May 11th, Cornell staff members in those research divisions reporting directly to the Office of the Vice Provost of Research (OVPR) were recognized for their years of service at the annual Research Division Service Awards ceremony hosted by Robert Buhrman, Senior Vice Provost for Research. The luncheon was held in the Statler Hotel Ballroom, and the CNF staff honored were, from left to right: Robert Buhrman, Sam Wright (40 yrs), Garry Bordonaro (30 yrs), Melanie-Claire Mallison (20 yrs), Edward Camacho (10 yrs), Dave Botsch (15 yrs), John Treichler (15 yrs), Michael Skvarla (over 40 years!), and Don Tennant (10 yrs). The awardees received the OVPR's thanks and a Cornell coffee mug. At the same luncheon, the staff of the OVPR office honored Robert also, on the occasion of his retirement from the VPR position. After ten years, Bob returns to teaching in the School Applied & Engineering Physics. CNF will miss his guidance, but we look forward to working with our new Senior Vice Provost for Research, Emmanuel Giannelis.

CNF Ambassadors Share Love of Science with Kids

By Beth Rhoades

2017 marks the second year of the CNF Ambassador Outreach program. A small, but dedicated, group of CNF users volunteered to share their love of science with youth in some amazing outreach activities. They helped 4-H'ers and disadvantaged students to make LED circuits using photolithography. Some judged the annual FIRST® LEGO® League Jr. Challenge Expo. A few put on a physics skit for middle school-aged girls that involved flames, leaf blowers, and a genie. Others visited NYC-area schools and showed teachers how to use nanotechnology lessons in their STEM curriculum. And there were many high school field trips that wouldn't have been nearly as interesting without the activities led by CNF users.

I'd like to extend a hearty thank-you to the wonderful 2017 CNF Ambassadors: Rose Agger (starred as the

Witch), Beth Curley (a.k.a. stage-hand extraordinaire), Hao Shi, Alex Ruyack, Melanie Roberts, George Calvey, Gabrielle Illava, Brian Schaefer, Andrea Katz, Isaiah Gray, Josue San Emeterio (starred as the Genie) as well as thanks to Sophia Rocco (starred as the Scientist) for stepping up for a last-minute performance!

I'd also like to thank the CNF staff that volunteered to help in many of these events, too.

The CNF Ambassador program is starting its third year, and we could use you! An organizational meeting will convene in December, so stay tuned.

If you have any questions, talk to one of the CNF Ambassadors about their experiences or contact me, Beth Rhoades, at err23@cornell.edu.



CNF Ambassadors put on a skit "It's not magic. It's Science!" at the 2017 Tech Savvy STEM Event for Girls. (From left to right, Josue San Emeterio, Sophia Rocco, Beth Curley and Rose Agger).



Honorary CNF ambassador, Sophia Rocco, shows a 9th-grader how to use Bernoulli's Principle to fill a bag with air at the 2017 Tech Savvy STEM Event for Girls.



CNF Takes on New Life

New biology-related capabilities and a campaign to welcome new life sciences researchers

By Beth Rhoades
October 20, 2017

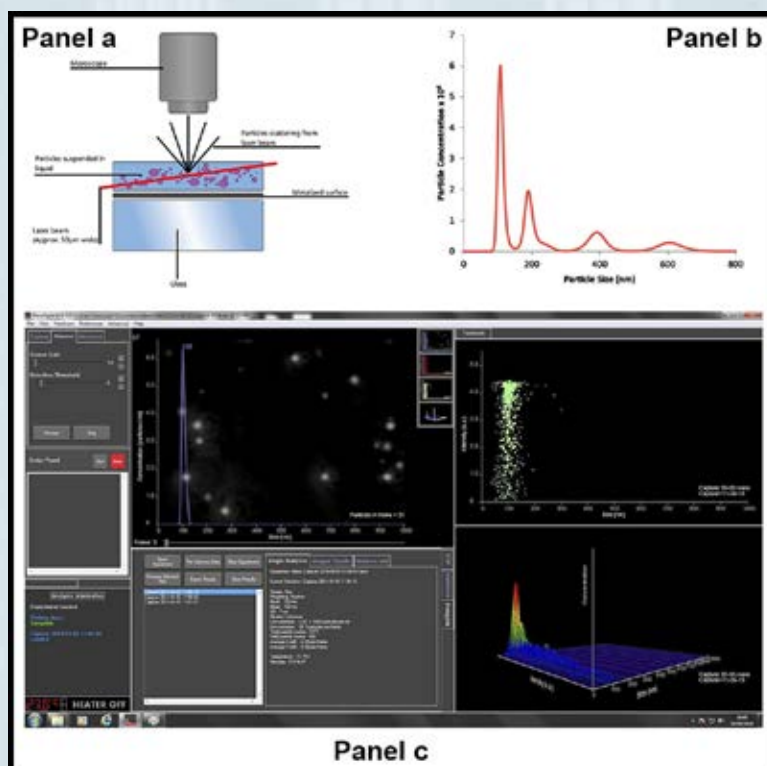
The closing of the Nanobiotechnology Center's doors in August, 2017 didn't spell the end for biology-related capabilities at the nanoscale. Most of the NBTC's tools were divided amongst three Cornell centers: the CNF, CCMR, and the Biology Resource Center.

The CNF has taken on more than a dozen tools and welcomed former NBTC users into the fold. And we offer a stream-lined second floor-only orientation for users who don't require access to our clean room. The tools that we assumed from the NBTC include:

- Malvern NS300 NanoSight
- Malvern Nano ZS Zetasizer
- Accurion EP3 Nanofilm Ellipsometer
- Olympus IX-71 Inverted Fluorescence Microscope
- Critical Point Dryer
- Samco UV Ozone Tool
- Rame-Hart 500 Contact Angle Goniometer
- Viscometer
- Labcoater Parylene Coater
- Dektak 6M Contact Profilometer
- CHA Mark-50 E-beam Evaporator
- Expanded Set of Ovens and Tools for Processing Polydimethylsiloxane (PDMS)
- Millipore DeIonized Water

The additions fall right in line with our plans to invigorate and update the life sciences capabilities at the CNF. We plan to do more. We recently met with a panel of researchers from academia, government and industry to assess today's key nanobiology needs. And we are reaching out to Cornell researchers for additional ideas on key fabrication and measurement capabilities.

If you have suggestions, please contact our life sciences liaison, Beth Rhoades (err23@cornell.edu).



An example of a tool in our newly acquired nanobiology toolset is the NanoSight NS300. It uses nanoparticle tracking analysis to characterize nanoparticles (NPs) in the range of 10 nm to 1000 nm on a particle-by-particle basis.

The schematic in panel A shows how laser light is diffracted and the scattered light is collected by a digital camera to track the Brownian motion of each particle. Particle size is calculated based on hydrodynamic radius and the Stokes-Einstein equation (Panel B). Particle concentration can be measured simultaneously. The software for data output allows users to see the individual particles and runs to gauge the quality of their samples (Panel C).

Currently, users are using the NanoSight to characterize exosomes and inorganic NPs, such as quantum dots.



Sunshine, Football and Dinner a Winning Combination

By Nancy Doolittle
October 10, 2017
Cornell Chronicle

With shirtsleeve temperatures and plenty of sunshine, spirits were high for Employee Celebration, Oct. 7. Winning a close Big Red men's football game against Harvard, 17-14, didn't hurt, either.

More than 3,000 Cornell employees, retirees and their families enjoyed barbeque chicken and pasta, served by Cornell President Martha E. Pollack, senior administrators, staff, students and retirees in Barton Hall. Children also enjoyed face-painting, spinning a wheel for prizes at the United Way of Tompkins County table, looking through a telescope from the Department of Astronomy and putting on clean room suits — with the help of Beth Rhoades, senior research associate and life sciences liaison for the Cornell NanoScale Science and Technology Facility.

"Thanks to everyone who volunteered for Employee Celebration," said Cheryl McGraw, human resources event manager. "We could not hold this event without all the efforts of our volunteer staff and students who came out on a beautiful fall day to help with setting up tables, serving dinner and cleaning up afterward."

Employee Celebration is sponsored by the Division of Human Resources, Cornell Catering, CFCU Community Credit Union, the Department of Athletics and Physical Education, the Division of Infrastructure, Properties and Planning, Utz and PepsiCo.

By the way..... the photographs at right of children in the clean room are an "optical illusion" — the kids are actually in Barton Hall standing in front of a pop-up screen with a photo from our cleanroom on it!



Clark, right, practices an experiment in a clean laboratory suit while brother Lima looks on.



National Nanotechnology Day Nano-Race!

For National Nanotechnology Day and to answer the question, "How fast can your mascot run 100 billion nanometers?" — Cornell University's Touchdown the Bear and CNF nano-researcher, Isaiah Gray, ran the football field (107 yards, actually) during the CU-Harvard football game on October 7.

It was a close race, but the bear won — running the 100 billion nanometers in 25.19 seconds!

ANNOUNCER SCRIPT: OK FOLKS! THE NATIONAL NANOTECHNOLOGY COORDINATION OFFICE SENT OUT A CHALLENGE, "HOW FAST CAN YOUR MASCOT RUN 100 BILLION NANOMETERS?" TO CELEBRATE NATIONAL NANOTECHNOLOGY DAY, WE'VE GOT TOUCHDOWN AND A RESEARCHER FROM CORNELL'S NANOSCALE SCIENCE AND TECHNOLOGY FACILITY. THE RESEARCHER HAS ON A CLEAN ROOM SUIT THAT IS WORN TO KEEP NANODEVICES CLEAN WHILE THEY'RE MADE IN CORNELL'S NANOSCALE FABRICATION FACILITY. IT LOOKS LIKE THEY'RE READY. ON YOUR MARKS....GET SET GO! (ONCE FINISHED) WHAT A RACE! GIVE IT UP FOR TOUCHDOWN AND THE RESEARCHER. TO FIND OUT MORE ABOUT SCIENCE AT THE NANOSCALE, VISIT THE FACILITY'S TABLE AT BARTON HALL DURING DINNER TONIGHT!

The race video and other CNF News can be found at http://www.cnf.cornell.edu/cnf_announcements.html

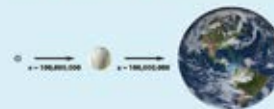
How fast can **YOUR MASCOT** run
100 BILLION NANOMETERS???



Upload a picture or video of your school's mascot running #100BillionNanometers for National Nanotechnology Day.
(There are 1 billion nanometers [1,000,000,000 nm] in 1 meter, so 100 billion nanometers = 100 meters)

#NationalNanoDay is October 9th!

National Nanotechnology Day features community-led events and activities to raise awareness of nanotechnology.



If a sphere 1 nm across were as big as a softball, a softball would be as big as the Earth!

Will your mascot measure up?

Let us know at NND2017@nncn.nano.gov

To learn more go to nano.gov/NND2017



#NationalNanoDay | #100BillionNanometers | #100BNM

Block Copolymer Lithography for Sub-25nm Periodic Features

Alexander Ruyack, CNF Fellow^{1,2}, Vince Genova², Alan Bleier²

1. School of Electrical and Computer Engineering,

2. Cornell NanoScale Science and Technology Facility,
Cornell University, Ithaca, NY, USA

Abstract/Summary

Nanolithography is a fundamental requirement for the future of electronics patterning. Current trends indicate the end of Moore's Law for traditional lithography processes. Directed self-assembly (DSA) of block copolymers (BCPs) can generate ordered, periodic arrays of various structures down to single nanometer (nm) size scale. The heterogeneous nature of these structures act intrinsically as their own mask, enabling nanometer-scale resolution with a flood exposure and no traditional photo mask. BCP lithography offers low-cost processing of nm-scale periodic structures typically only available by e-beam lithography, and can act as a complementary technology to conventional photolithography.

In this work, we develop a PS-*b*-PMMA BCP lithography process on SiO₂/silicon using CNF labs and tools, achieving ~20 nm pattern resolution.

Process Information

BCP lithography relies on the microphase separation of the two comprising polymers to achieve a nanoscale pattern. Due to the reliance on self-assembly, the resulting photolithographic features are intrinsically periodic. As such, this process is useful for applications in areas where long range repeating structures are needed, such as nano-porous substrates, nanoparticle synthesis, or high-density information storage media.

For the development of this method, we used a poly(styrene-*block*-methyl methacrylate) (PS-*b*-PMMA) block copolymer due to its popularity in literature, which stems from its excellent etch selectivity, low surface energy mismatch, and theoretical 12 nm feature size.

The typical fabrication flow for a BCP lithographic process is shown in Figure 1 (left) (adapted from [1]). First, a surface treatment is applied to create a neutral layer/brush. This prevents a surface parallel BCP domain orientation from occurring by making the substrate surface interfacial energy equal for both polymer phases. Next, the BCP is spin-coated and then thermally annealed allowing for phase separation and formation of the pattern. Finally, one phase is selectively removed and subsequent substrate processing can occur from this point.

We used P9085-SMMaranOHT as our neutral layer and P8205-SMMA as our BCP (both obtained from Polymer Source). Our process flow follows that shown in Figure 1 (right), where the etch is accomplished using a 220 nm flood exposure followed by an acetic acid dip. Various polymer concentrations, film thickness, and anneal conditions were tested for their effect on pattern formation (morphology, uniformity, periodicity, etc.). Figure 2 shows the resulting BCP thickness as a function of two solution concentrations (1 and 2% in toluene) and spin speed showing achievable thicknesses ranging from 30-150 nm. Figure 3 shows SEM micrographs of the BCP at various points in fabrication.

In order to quantify the effect of our parameter sweeps it was necessary to develop an image processing technique that could quickly evaluate samples.

We used ImageJ to develop two separate macros for 1) measuring feature sizes, and 2) evaluating inter-feature spacing. In our case, the BCP morphology is a hexagonal array of pores, so these methods were tuned to generate information on pore diameter and interpore spacing.

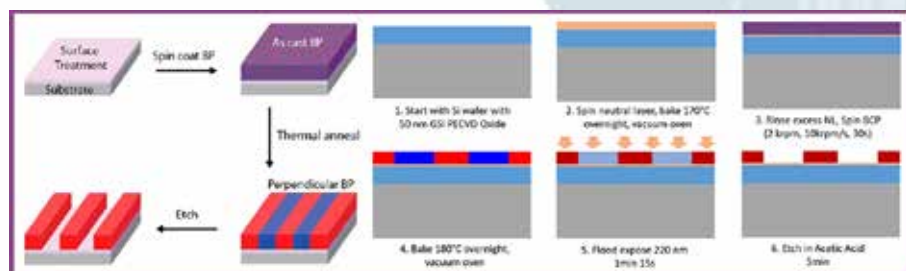


Figure 1: Left: Typical BCP lithography fabrication flow (adapted from [1]). Right: Fabrication flow for PS-*b*-PMMA BCP.

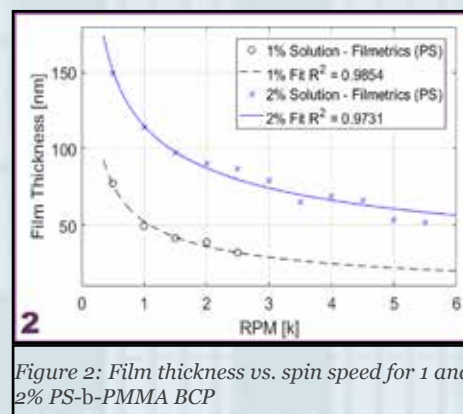


Figure 2: Film thickness vs. spin speed for 1 and 2% PS-*b*-PMMA BCP

The former was accomplished using built in ImageJ functions and the Particle Analysis tool. The latter is comprised of built in ImageJ functions along with an additional macro for K-Nearest Neighbor analysis that was expanded on from an existing implementation, as well as a custom Matlab script [2]. Figure 4 shows the visual output of these macros.

Through this system of evaluation, we were able to achieve BCP films of 30 nm thickness with long range order. Pore sizes of ~ 23.12 nm with 1.78 nm standard deviation and interpore spacing of ~ 54.26 nm with 7.33 nm standard deviation and a circularity of ~ 0.92 were obtained. Figure 5 shows example SEM images of a typical sample. Using these films, pattern transfer through 50 to 100 nm of oxide has been achieved, as well as a subsequent Si etch (Figure 6).

In the future, we are working on various paths forward for BCP lithography implementation at the CNF. One path is further process tuning to reduce defects in the film and improve uniformity and periodicity.

Beyond this, we are also looking into additional processing steps required to alter the BCP film morphology. In particular, we are working on a graphoepitaxy process that will result in parallelly aligned domains, rather than pores. Finally, we are also investigating other BCP systems for smaller features sizes (<10 nm), such as PS-b-PDMS.

References

- [1] C.M. Bates, et al., *Block Copolymer Lithography*, *Macromolecules*, 2014, 47 (1), pp 1-12.
- [2] Burri, Olivier, *2D K Nearest Neighbors Python script*, (2017), GitHub repository, <https://gist.github.com/lacan/2643f2ce7e33d1bb07adafde9ff94101>

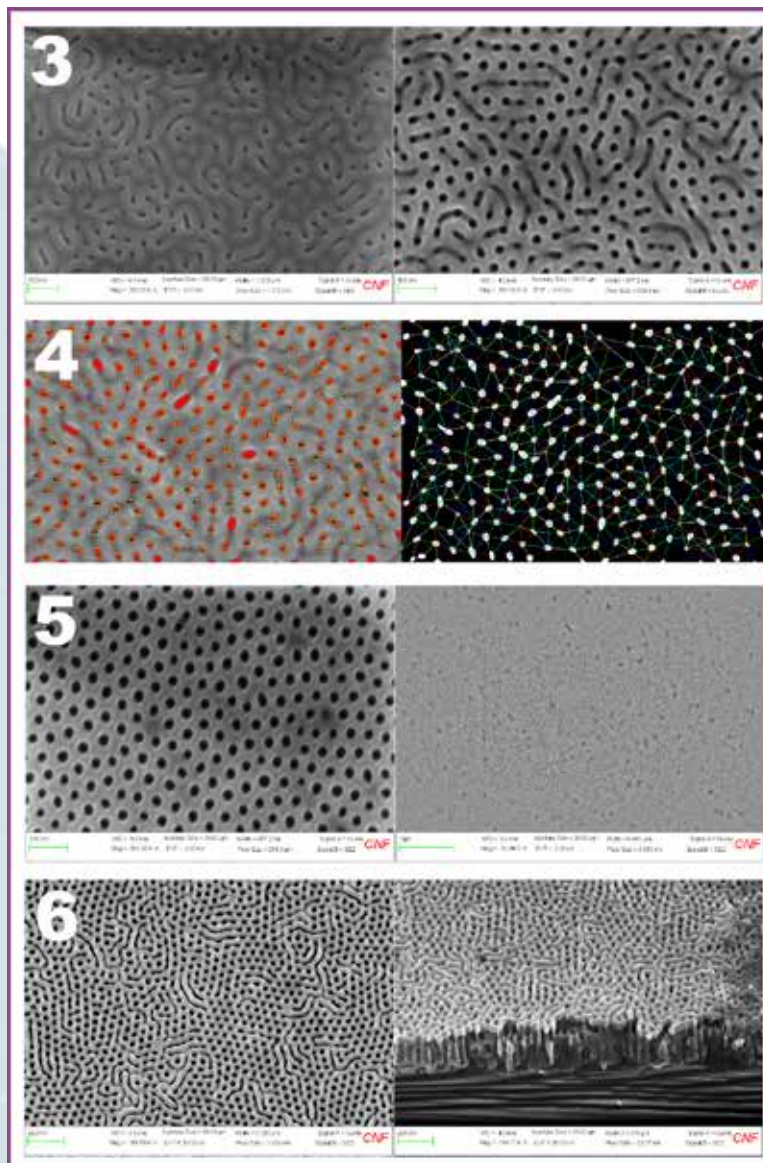


Figure 3: SEM micrographs of BCP film. Left: after annealing. Right: after etching. The increase in contrast comes from the removal of the PMMA phase in the pore regions after the etch. Figure 4: Output of ImageJ macros. Left: Pore size analysis with designated pores shown in red. Right: K-Nearest Neighbor Analysis with lines corresponding to six nearest neighbors. Figure 5: SEM micrographs of optimized BCP film. Left: 350kx magnification showing pore diameter and interpore spacing uniformity. Right: 50kx magnification showing long range order. Figure 6: SEM micrograph of BCP on 50nm of SiO₂ on Si after CH₂F₂/He and HBr/Ar etch. Left: Top down. Right: Cleaved, 45 degrees.

Six Faculty Honored with Weiss Teaching Awards

By Daniel Aloï
October 20, 2017
Cornell Chronicle

Six Cornell faculty members have been recognized by the university for excellence in their teaching of undergraduate students and contributions to undergraduate education — receiving a Stephen H. Weiss Presidential Fellowship — including **Tomas Arias**, professor of physics and CNF principal investigator. The fellowship awards were announced by President Martha E. Pollack on October 20 at a meeting of the Cornell University Board of Trustees. The award winners are chosen by a selection committee comprising emeritus faculty, current Weiss fellows and undergraduate students.



Tomas Arias

“These are among Cornell’s highest honors for outstanding, exemplary teachers,” Pollack said. “The committee reviewed thousands of pages of material and engaged in spirited discussions to identify deserving candidates. I was pleased to accept the selection committee’s choices, and commend their commitment and diligence in putting forward truly outstanding candidates.”

Established in 1992, the Weiss Presidential Fellowship was conceived by the late Stephen H. Weiss '57, chairman emeritus of the board of trustees, to recognize tenured Cornell faculty members for teaching and mentoring undergraduates. In addition to a respected scholarly career, the recipients have sustained records of effective, inspiring and distinguished teaching and contributions to undergraduate education.

Chao Sun (PhD student, Dichtel group, Department of Chemistry and Chemical Biology) was awarded the RIKEN prize from among over 140 posters at the 2017 Self-Assembly & Supramolecular Chemistry Gordon Research Conference in Switzerland. His poster presentation was titled ‘Discovering Supramolecular Adhesives for Atomic Membranes.’ This work is in collaboration with Professor Paul McEuen’s group and conducted at CNF.



2013 CNF REU Intern, **Caleb Christianson**, has a new publication, in Soft Robotics; “A Biologically Inspired, Functionally Graded End Effector for Soft Robotics Applications”; Kitty Kumar, Jia Liu, Caleb Christianson, Mustafa Ali, Michael T. Tolley, Joanna Aizenberg, Donald E. Ingber, James C. Weaver, and Katia Bertoldi. Soft Robotics. October 2017, <http://online.liebertpub.com/doi/10.1089/soro.2017.0002> (Selfie from 2013 in the CNF cleanroom with CNF REU interns, left to right; Caleb, Kris Beykirch, Tyler Erjavec, Maïke Blakely (in front), and Rafael Haro)

Prateek Sehgal from KirbyLab won the W. Terence Coakley Award at the Acoustofluidics 2017 conference in San Diego for the best poster presentation. The conference is focused towards the science and engineering of micro- and nanoscale acoustofluidics. URL: <https://cbmsociety.org/conferences/acoustofluidics-2/>



Thanks to Amrita Banerjee and Sam Wright for bringing filter elements that provided for our wonderful viewing of the eclipse on August 21, 2017. Using Amrita’s eclipse glasses, I was able to get a few decent pics. They were taken at 2:42, 2:44, and 2:52 PM. Quite a show! Don Tennant

Gary Harris '75 Given Alumni Honor for Diversity, Inclusion Efforts

By Daniel Aloï
August 17, 2017
Cornell Chronicle



Hernández, left, presents Gary L. Harris with the inaugural Turner Kittrell award. Lindsay France/UPhoto.

On August 16th, Gary L. Harris '75, M.S. '76, Ph.D. '80, was honored by the Cornell Graduate School with the inaugural Turner Kittrell Medal of Honor. The award was established to recognize alumni who have made significant national or international contributions to the advancement of diversity, inclusion and equity in the academy, industry or the public sector. Recipients are chosen by the Graduate School Diversity Advisory Council.

Harris studied electrical engineering throughout his Cornell career. He is a professor of electrical engineering and materials science and associate provost for research and graduate studies at Howard University, and director of the Howard Nanoscale Science and Engineering Facility and is the former director for the Howard node of the National Nanotechnology Infrastructure Network (NNIN).

Sara Xayarath Hernández, associate dean for inclusion and student engagement at the Graduate School, presented Harris with the award Aug. 16 at the end of the Summer Success Symposium for underrepresented M.S./Ph.D. and Ph.D. students from all graduate fields. Harris was the event's keynote speaker. "In a 1986 article for U.S. Black Engineer," Hernández said, "Dr. Harris explained that it was his interest in the black community that empowered him to make his career at Howard. He stated, 'I felt I could multiply myself here.'

"At the time he graduated from Cornell, Dr. Harris was among a small number of African-Americans with a doctorate in electrical engineering. Though he could have gone into industry, he made an intentional decision to pursue a career in the academy, where he has helped to broaden the participation of those historically underrepresented in higher education, and where he has achieved great success as a researcher, scholar and leader within graduate education." Harris played a pivotal role in establishing the Edward A. Bouchet Graduate Honor Society in 2005, which "now has 15 chapters including our own chapter," Hernández said, and fosters a network of preeminent scholars from underrepresented backgrounds.

"He is also responsible for helping Howard maintain its leadership role as the number one producer of on-campus African-American Ph.D.s in the nation," Hernández said.

Harris' other honors include the National Society of Black Engineers' Scientist of the Year Award. He has

published more than one hundred peer-reviewed articles, edited five books, presented more than two hundred papers at conferences, and mentored and advised the research theses and dissertations of more than 150 master's and Ph.D. graduates.

"Let me just say in honor of all the students that I've had an opportunity to interact with, I am just floored by this honor," Harris said. "I can't wait to get back to Howard and share this with my colleagues. ... I'm only accepting it in honor of all the students that I've worked with — because, you know, awards are given to individuals, but the work that I do is a team effort."

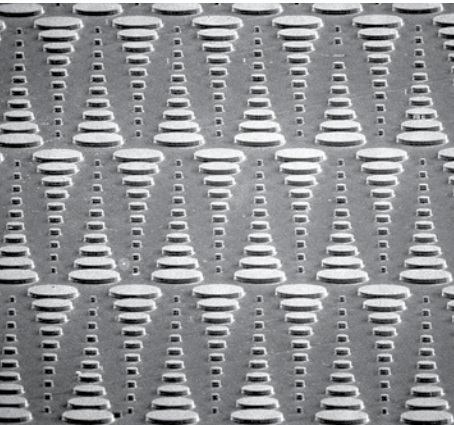
The award is named for educators and activists Thomas Wyatt Turner, Ph.D. '21, and Flemma Pansy Kittrell, M.A. '30, Ph.D. '36, the first African-American man and woman to earn doctoral degrees from Cornell. Like Harris, Howard University also figured in their post-Cornell careers.

"These two individuals are legends on Howard's campus," Harris said. "They defined the whole essence of facts and science and engineering and technology, and were the inspirations for literally thousands of people."

Turner studied botany at Cornell and taught at Howard between 1914 and 1924, and at Hampton from 1924 to 1945. A founding member of the National Association for the Advancement of Colored People in 1909, he fought for justice for blacks throughout his life.

In 1924 Turner encouraged Kittrell, who had a home economics degree from Hampton, to consider graduate studies at Cornell.

The first African-American woman in the country to earn a Ph.D. in nutrition, Kittrell was an example for minorities pursuing a university education and an international pioneer in nutrition and child development. She was instrumental in creating the federal Head Start Program, and as a Fulbright scholar she established a home economics college and a nutrition research program at Baroda University in India.



JANUARY 2018 CNF TCN Now ONLINE

**TUESDAY - FRIDAY,
JANUARY 9 - 12, 2018**

**In January 2018, the
Cornell NanoScale Science
& Technology Facility
is offering an intensive
3.5 day short course on**

TECHNOLOGY & CHARACTERIZATION AT THE NANOSCALE (CNF TCN)

*This non-credit course combines
lectures and laboratory demos designed
to impart a broad understanding
of the science and technology required
to undertake research in nanoscience.*

**ATTENDANCE IS OPEN
TO THE GENERAL
SCIENTIFIC COMMUNITY,
BUT CLASS SIZE IS LIMITED.**

**[http://cnf.cornell.edu/
cnf_tcn_january_2018.html](http://cnf.cornell.edu/cnf_tcn_january_2018.html)**

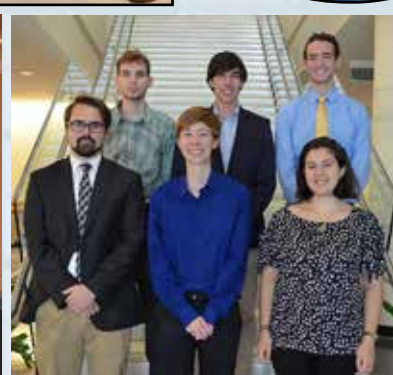
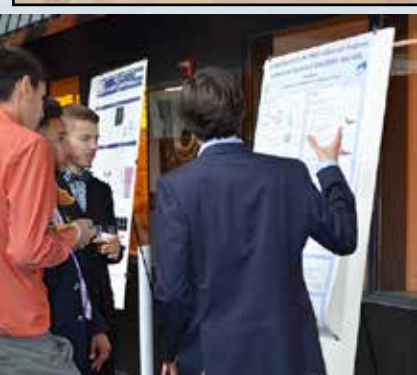
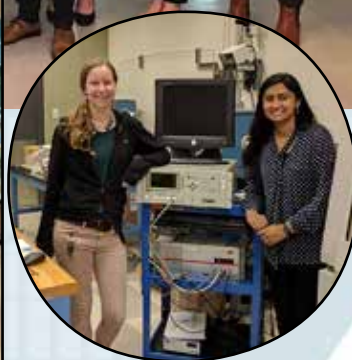




Over the summer of 2017, four Research Experience for Undergraduates (REU) programs got together to share logistics, trainings, presentations, and a lot of good food! All told, Cornell NanoScale Science & Technology Facility (CNF), Howard Hughes Medical Institute EXceptional Opportunities Program (HHMI EXROP), Keeping the Ezra Promise (KEP), and Platform for the Accelerated Realization, Analysis, and Discovery of Interface Materials (PARADIM) hosted sixteen interns on Cornell campus + the CNF hosted its international program with six interns from our 2016 network (NNCI) REU Programs traveling to the National Institute of Material Science (NIMS), Tsukuba, Ibaraki, Japan. Many thank yous to all the interns for a successful summer!

A complete list of our interns with their final reports and presentations can be found at http://www.cnf.cornell.edu/cnf_2017reu.html

The 2018 CNF & PARADIM REU application is online now at <http://www.reu.nnin.org>



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Your comments are welcome!

