NanoMeter

The newsletter of the Cornell NanoScale Science & Technology Facility

Winter 2007-2008 • Volume 17, Number 2

Directors' Column

It is with great pleasure that we present the 2007 Winter issue of NanoMeter. One of the highlights of 2007 was our 30th anniversary celebration last June. The one day "Future of Nanotechnology" symposium was a major success, attended by over 400 people from academia, industry, and government. Three tracks covered (i) future trends in nanotechnology, (ii) the emerging field of nanomedicine, and, (iii) social and ethical issues associated with nanotechnology. All tracks were well attended, indicating the broad range of interests of the nanotechnology community associated with CNF. Videos of the presentations and a collection of photographs from the event are available at: http://www.cnf.cornell.edu/cnf_nanofutures.html. More symposium "afterglow" can be found within this issue.

The Cornell NanoScale Facility (CNF), and nanotechnology in general, received a lot of publicity following this symposium. This resulted from the Kavli workshop for journalists, held the day before our symposium, and the involvement of the Cornell office for communications and media relations. Among the most notable pieces of publicity were the *Science Friday* panel discussion on nanotechnology and an *Associated Press* story on the benefits of CNF to nanotechnology companies. The widespread publicity is obviously welcome, as it helps us reach out to a broader audience and call attention to the benefits of being associated with CNF.

In this issue you will also read about our latest technology results in etching and some leading nanoresonator work taking place at CNF. Many more research highlights can be viewed in our latest edition of the CNF Research Accomplishments (available on our website, www.cnf.cornell.edu).

Next on our horizon is a workshop on the commercialization of nanotechnology. This new endeavor for CNF, in which we will partner with the Central New York Technology Development Organization, has a dual purpose: To educate the CNF community on how to start a small company, and to educate small companies on the services provided by CNF and other state-of-the-art facilities at Cornell and in the region. The program will include "how I did it" talks by people whose work at CNF led to commercialization, as well as talks on intellectual property issues and funding opportunities for small companies. A reception and a poster session will provide participants with networking opportunities. The day for this workshop is set for April 10th 2008. More information will appear on our website soon. We look forward to seeing many of you at this workshop.

In This Issue...

Header SEM: Synthetic poly(dimethylsiloxane) fibrillar surface with terminal film. CNF Project # 1225-04, "Mimicry of Biological Adhesion Through Fabrication of Fibrillar Surfaces." Principal Investigator: Anand Jagota, Users: Nicholas J. Glassmaker, Shilpi Vajpayee, Affiliation: Chemical Engr, Lehigh University.

Cornell NanoScale Science and Technology Facility

30th Anniversary, 1977–2007

CNF reflects on past, looks to future of nanoscience at 30th anniversary celebration

By Anne Ju
Updated by Melanie-Claire Mallison

The Cornell campus buzzed with over 400 participants at the 30th anniversary celebration of the Cornell NanoScale Science and Technology Facility (CNF), June 14, 2007. Topics addressed included drug delivery, ethics and even science fiction.

Scientists from all over the country and world, including many from Cornell, gathered to hear expert speakers, participate in technical sessions and attend a research poster presentation at day's end.

The anniversary symposium, "The Future of Nanotechnology," kicked off with reflections from Edward Wolf, professor emeritus of electrical and engineering, and CNF director from 1978 to 1988. He recounted that in the early years, CNF was called the National Research and Resource Facility for Submicron Structures. "Nano" was not part of the title until 1987, when the facility was renamed the National Nanofabrication Facility. In 2003, CNF took on its present name.

Despite these iterations, CNF has long been connected closely with the National Science Foundation (NSF), which has provided the majority of CNF funding during its entire existence.

Lawrence Goldberg, senior engineering adviser of NSF's Division of Electrical and Communications Systems, called CNF a "vibrant enterprise" that has surpassed its founding concept and evolved into a world leader in nanoscience and nanofabrication.

"The National Science Foundation is very proud to have played a continuing role in that success," said Goldberg, who oversees the National Nanotechnology Infrastructure Network, a 13-member consortium, including Cornell, of nanoscience-focused institutions.

The CNF plenary speakers; top left, R. Stanley Williams, botom left, Tejal Desai, right, Sheila Jasanoff. All pictures in this article are by Charles Harrington Photography.

The day's themes were laid out by three additional speakers. R. Stanley Williams, a senior fellow at Hewlett-Packard Laboratories, described the advances he and others at his company have made in nano-imprint lithography.

The technique, which is a progression from the more traditional method of photolithography for creating nanoscale devices, involves creating a mold of a device to stamp — not unlike a rubber stamp — an imprint of the device as a way of copying it.

Introducing the topic of nanomedicine, Tejal Desai, director of the University of California-San Francisco's Laboratory of Therapeutic Micro and Nanotechnology, spoke about therapeutics and drug delivery using nanotechnology. Nanomedicine, she said, continues to face the challenge of developing drugs or therapies that can be taken orally and are able to withstand the physiology of the digestive system.

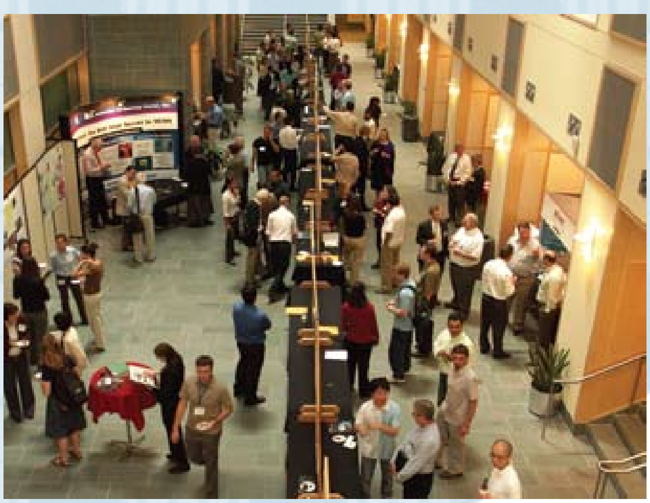
The third plenary speaker, Sheila Jasanoff, professor of science and technology studies at Harvard University who also was founding chair of Cornell's department of the same name, spoke on the politics and societal implications of nanotechnology.

While drawing comparisons between public perceptions of nanotechnology and the Manhattan Project or genetically modified foods, she also noted that built into the early stages of nanotechnology research is a widespread desire to take social and ethical considerations seriously. She urged the use of "technologies of humility," and to proceed with nanoscience breakthroughs "grounded in memory and experience."

Following the plenary speakers, the participants spent the afternoon in tracks dedicated to each of the three topics.

Phaedon Avouris, manager of Nanometer Scale Science and Technology at IBM's T.J. Watson Research Center, addressed present and future promise of carbon nanotubes in terms of electronics and optoelectronics. Michael Sheetz, chair of Columbia University's Nanotechnology Center for Mechanics and Regenerative Medicine, discussed cellular mechanics through nanotechnology. And Rosalyn Berne, associate professor of science, technology and society at the University of Virginia, in discussing the social and ethnical dimensions of nanotechnology, suggested science fiction as a portal to ethics in nanotechnology.

CNF rounded off the day filling the Duffield Hall atrium with research posters, corporate sponsors, and good food. Three Best Poster awards were presented, as was the CNF's Nellie Yeh-Poh Lin Whetten Memorial Award, given annually to an outstanding, collaborative female graduate student whose work was carried out at CNF.



***The CNF Directors:** Top; **Edward Wolf** with Whetten Award Winner, Sharon Gerbode; next, **Joseph Ballantyne** with **Harold Craighead**; next, **John Silcox** enjoying a laugh with Maura Weathers from CCMR; bottom, **Noel MacDonald**, Donald Tennant (CNF Director of Operations) and **George Malliaras**, CNF's present Director.*

Cornell scientists Barbara Baird and John Silcox talk up nanotechnology on NPR's 'Science Friday'

By Anne Ju
Updated by Melanie-Claire Mallison

"...The lab turned 30 this week and they threw a symposium to celebrate." Ira Flatow, starting off Science Friday, June 15

From devices that recognize diseases before symptoms appear to sensors that detect toxins in the environment, people across the nation tuning into National Public Radio (NPR) June 15 heard from Cornell scientists about such potential breakthroughs that nanotechnology promises.

Barbara Baird, Cornell professor of chemistry, and John Silcox, Cornell professor of applied and engineering physics, were among the featured guests on "Science Friday," part of NPR's "Talk of the Nation" radio program. The broadcast took place on the heels of the Cornell NanoScale Science and Technology Facility (CNF) 30th anniversary symposium the previous day.

"We were nano before nano was cool," said Silcox while being interviewed by the show's host, Ira Flatow.

Also participating in the hour-long interview were Rosalyn Berne, associate professor of science, technology and society at the University of Virginia, and Lawrence Goldberg, senior engineering adviser of the National Science Foundation's (NSF) Division of Electrical and Communications Systems, who joined Baird and Silcox for the broadcast from Fall Creek Studios near downtown Ithaca.

The four interviewees spoke on the promises, breakthroughs and potential ethical perils of nanotechnology.

Given unlimited funds, Flatow asked, what innovations could nanotechnology one day bring to the world?

For Baird, the best way to answer the question was to think of the world's problems — lack of clean drinking water, for one. Using nanotechnology, she said, scientists might someday perfect a membrane or combination of devices that could immediately sense problems with a water sample and filter them out quickly.

"That requires a combination of things, not just one thing," Baird said. "Nanotechnology is one tool, and it's to be put together with a variety of other tools to be maximally effective."

Flatow also asked whether enough attention is being paid to ethical issues and potential dangers of nanotechnology.

Goldberg said that along with nanotechnology research funding, NSF has invested heavily, for example, in initiatives with the Department of Energy and Environmental Protection Agency to look at science issues and their risks.

"I think the federal government is placing an emphasis on this aspect," Goldberg said.

Berne, who studies ethnical, cultural and societal implications of nanotechnology, said she has interviewed close to 35 scientists on such topics. She has found that scientists are often interested in ethnical considerations but don't always turn the questions inward, because they themselves are conscientious and feel they are doing the right thing. She added that finding opportunities to discuss such issues publicly are only now becoming more widespread.

"There are very few fora for actually dialoguing about this," Berne said.

The scientific breakthroughs in nanotechnology have been enormous, said Silcox, with many of them focusing on techniques to fabricate or image nanometer length scales. For example, Silcox said great strides are being made in electron microscopy for analyzing nano-sized particles with greater depth.

In general it is hard to predict where Cornell and nanotechnology will be in another 30 years, the speakers said.

"The only safe prediction is — you ain't seen nothing yet," Silcox said.

Audio of the program is available online at http://www.sciencefriday.com/pages/2007/Jun/hour2_061507.html

Nellie Whetten Memorial Award Winner: Sharon Gerbode

Sharon Gerbode, a current Ph.D. candidate in physics at Cornell University, is the 2007 recipient of the Nellie Yeh-Poh Lin Whetten Award. This award is presented annually to an outstanding female graduate student whose spirit, courtesy, and commitment to professional excellence are reminiscent of the late Nellie Whetten.

Sharon started the physics graduate program at Cornell in 2004, after receiving her B.S. in physics from University of California Santa Cruz. In pursuit of an outstanding graduate education, she gave up the warm beaches of Santa Cruz for the beautiful but often frigid hills of Ithaca. After surviving her first real winter, she joined the research group of Itai Cohen, a new physics faculty member interested in soft condensed matter.

Itai guided her into an interdisciplinary collaboration including Stephanie Lee and Chekesha Liddell in Materials Science and Engineering, and Bettina John and Fernando Escobedo in Chemical Engineering. Sharon became interested in hollow silica colloidal "peanuts" consisting of two connected spherical lobes, fabricated by the Liddell group. Because of their dimer-like shape, these peanut particles can fit into the same, well-known structures formed by hard spheres, indicating that the study of colloidal peanuts may constitute a simple but fundamental extension of the vast body of knowledge on crystals of colloidal spheres. She was privileged to be the first person to observe an ordered phase formed by a monolayer of the colloidal peanuts, in which the peanut particle lobes occupy triangular lattice sites, much like close-packed spheres, while the connections between lobe pairs are randomly oriented, uniformly populating the three crystalline directions of the underlying lattice (Figure 1).

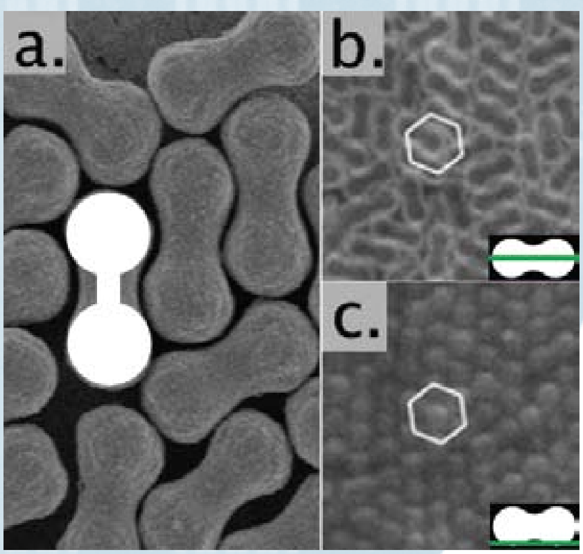


Figure 1: Peanut-shaped colloidal particles order into a "lobe-close-packed" (LCP) phase. (a) SEM image of the particles. (b) Confocal microscopy allows imaging a focal slice directly through the center of the particles, revealing apparently disordered hollow peanuts. (c) In the exact same location, a slice through just the particle tips is reminiscent of hexagonally close-packed spheres. All figures provided by Gerbode.

Sharon observed that many properties of these "lobe-close-packed" (LCP) crystals of peanut particles mimic those of crystals of colloidal spheres, with one striking exception. Crystal defects in LCP crystals seemed to move more slowly than those in crystals of spheres. In an effort to understand how crystal defects move in LCP crystals compared to crystals of colloidal spheres, Sharon directly observed dislocation nucleation and glide in LCP crystals under shear.

She discovered that the distance that a dislocation could glide was severely limited by geometric constrains imposed by interlocking peanut particles. Dislocations in LCP crystals under shear must use additional mechanisms, such as dislocation reactions, to circumvent roadblocks formed by the peanut particles. Consequently, in stark contrast to colloidal monolayers of close-packed spheres, dislocation pair nucleation is not the only significant energetic barrier to relieving an imposed shear strain.

The kinetic restrictions on glide have staggering implications for the plasticity of LCP crystals. If dislocation reactions are the only method for getting beyond geometric obstacles to glide, then a conservative estimate of the cost of shearing an LCP crystal of width N lattice constants is still greater than the cost to shear a crystal of close-packed spheres of identical size N by a factor of N/ln(N) (Figure 2). This divergently large energy cost implies that the shear

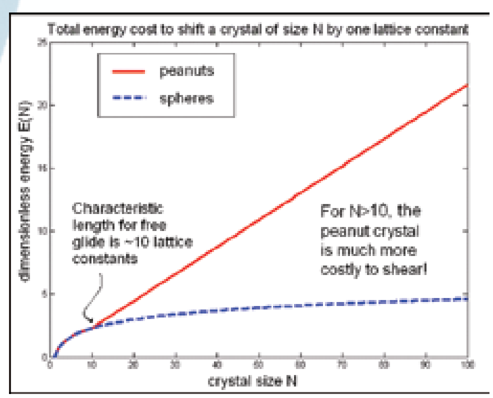


Figure 2: Assuming that dislocation reactions are used to navigate geometric obstacles formed by interlocking peanut particles, the energy cost to shear an LCP crystal can be estimated. Even a very conservative estimate of this cost is divergently larger than the cost for shearing a crystal of close-packed spheres, as the size N of the crystal increases beyond the characteristic length for unobstructed glide.

strength of LCP crystals may be much higher than that of close-packed spheres.

In addition to doing research on defects in colloidal crystals, Sharon also leads a weekly tutoring group at Lansing Residential Center, a nearby juvenile detention center for young women. She and her fellow volunteer tutors travel out to the facility weekly to work one-on-one with the students at Lansing. Originally an independent endeavor amongst interested physics graduate students, the Lansing tutoring program recently teamed up with the REACH program at the Public Service Center on campus, which has made the group much more visible. On tutoring at Lansing, Sharon says, "As a physics graduate student, I want to share my scientific curiosity with the young women at Lansing. Hopefully, by telling my personal story, I can make the path towards studying science seem more tangible and accessible for others."

Figure 3: Sharon Gerbode on a road trip.

Sharon Gerbode with her Whetten award.
Photo by Charles Harrington Photography.

30th Poster Award Winners

Three poster awards were given out during the CNF 30th Anniversary Poster Session. The awards were sponsored by __, presented by, from left to right, Edward Wolf, George Malliaras and Donald Tennant, and were given to (from left to right):

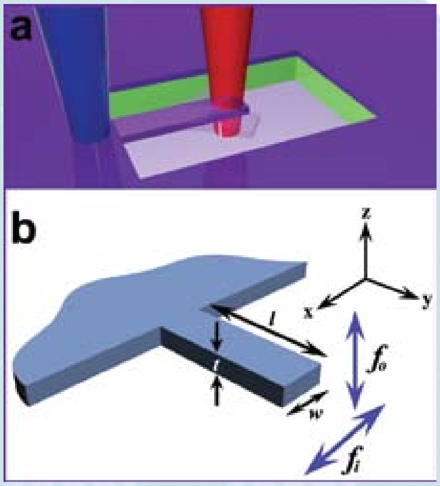
"Optofluidic Propulsion Using NanoPhotonic Structures" presented by Allen Yang, Chemical and Biomolecular Engineering, Cornell University. CNF Project Number: 1516-06; Principal Investigator: Prof. David Erickson.

"Electroactive Microfluidic Devices for Control of Insect Cyborg Neuromuscular Systems" presented by Aram Chung, Sibley School of Mechanical and Aerospace Engineering, Cornell University. CNF Project Number: 1516-06; Principal Investigator: Prof. David Erickson

"Quantitative Measurements of Spin-Transfer Torque in Magnetic Tunnel Junctions" presented by Yong-Tao Cui, Physics, Cornell University. CNF Project Number: 598-96; Principal Investigator: Prof. Daniel Ralph.

Side-to-side shaking of nanoresonators throws off impurities, researchers find

By Bill Steele



Schematic of the experimental setup. A laser striking the base of a cantilever (blue) can excite vibrations either in the plane or perpendicular to it, depending on the frequency at which the laser is pulsed. A 2nd laser (red) measures side-to-side motion as the cantilever chops through it. Courtesy of R. Ilic.

Tiny vibrating silicon resonators are of intense interest in nanotechnology circles for their potential ability to detect bacteria, viruses, DNA and other biological molecules.

Cornell researchers have demonstrated a new way to make these resonators vibrate "in the plane" — that is, side to side — and have shown that this can serve a vital function: shaking off extraneous stuff that isn't supposed to be detected.

The research is reported in the July 14 online version of the journal Nano Letters and in the August print edition.

The typical resonator is a cantilever — a narrow strip of silicon a few millionths of a meter long that can be made to vibrate up and down like a diving board just after someone jumps off. In research aimed at building the much-sought "lab on a chip," Professor Harold Craighead's group at Cornell and other researchers have shown that by binding antibodies to such resonators they can cause pathogens to attach to them. At the nanoscale, just adding the mass of one bacterium, virus or large molecule is enough to change the resonant frequency of vibration of the cantilever by a measurable amount, thereby signaling the presence of the pathogen.

But "If, for example, you are trying to detect E. coli, there will be more things in the fluid than E. coli, and they can weakly absorb on the detector by electrostatic forces. This is a problem in any sort of biodetection," explained B. Rob Ilic, a researcher in the Cornell NanoScale Facility. The answer, he said, is to make the resonator vibrate from side to side. This will shake off loosely adhered materials, while whatever is tightly bound to an antibody will stay put.

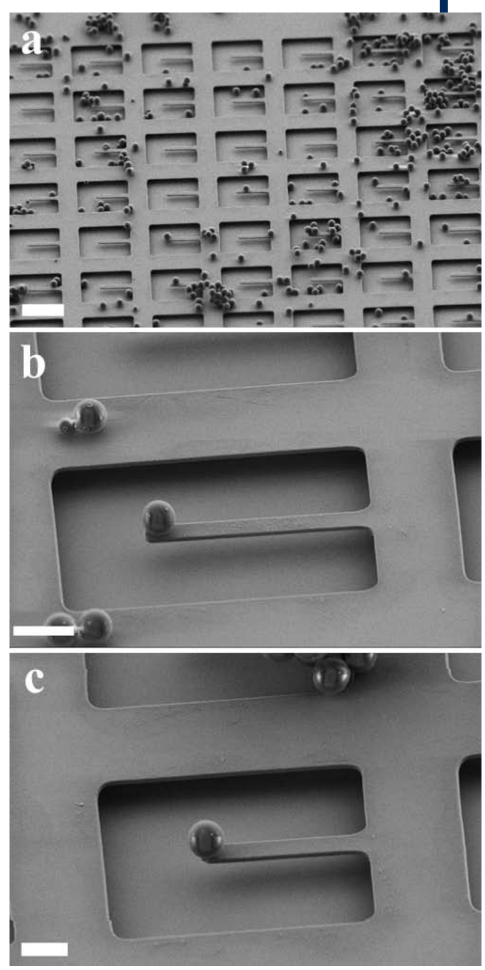
Ilic and colleagues made cantilevers about a micron wide, 5 or 10 μm long and 200 nm thick, suspended over an empty space about a micron deep. When energy was pumped in from a laser or by an attached vibrating piezoelectric crystal, the cantilevers vibrated up and down at a resonant frequency that depended on their dimensions and mass.

Then the researchers demonstrated that in-plane motion can be created by hitting the base of the cantilever with a laser pulsed at the resonant frequency of the cantilever's in-plane vibration, which is different from the resonant frequency of its vibration perpendicular to the plane. To measure in-plane motion the researchers shined another laser on the free end of the cantilever and detected the chopping of the beam as the cantilever moved from side to side.

To show that in-plane motion could shake unwanted materials off of biosensors, the researchers distributed polystyrene spheres ranging from half a micron to a micron in diameter onto an array of cantilevers. The spheres, which attached themselves by electrostatic attraction, were removed by in-plane shaking. But when the cantilevers were made to vibrate more intensely up and down — even so far that they bumped the "floor" below — the spheres did not budge, nor did they during spinning of the entire chip.

In-plane vibration also could be used to determine how strongly particles are bound to the surface by observing how hard they need to be shaken to come loose, Ilic said. The ability to excite in-plane motion also has applications in making nanoscale gyroscopes, in nano optics and for basic physics experiments, he added.

Co-authors with Ilic and Craighead are Slava Krylov, professor in the Department of Solid Mechanics, Materials and Systems at Tel Aviv Univ., and Marianna Kondratovich, an undergraduate researcher in Mechanical & Aerospace Engr.



SEMs of polystyrene spheres distributed on an array of nanofabricated Si cantilevers, where they adhere by electrostatic forces. Making the cantilevers vibrate violently up and down won't shake such materials off, but shaking from side to side will. Courtesy of R. Ilic.

Etcetera

Cornell gets high marks from peer institutions in Small Times nanotechnology rankings

By Anne Ju

Small Times magazine's third-annual survey of top nanotechnology institutions placed Cornell in the top 10 of every category listed, including research, education and facilities. Cornell also received high marks from peer institutions for its research and commercialization abilities.

The nanotechnology trade magazine calculated Cornell as second overall among nanotechnology institutions, behind only University at Albany, State University of New York. The overall ranking was generated from questionnaires sent to dozens of scientists at research institutions who answered 26 questions about their nanotechnology programs.

In the overall ranking categories, Cornell was fourth in research, fifth in commercialization, sixth in facilities and 10th in education.

> "Cornell encourages interdisciplinary academic programs and research," Small Times noted about Cornell. "Its innovations include its nanofabrication facility and discovery in the field of nanobiotechnology. The university's mission is to generate new knowledge about micro- and nanoscience, and then to transfer that knowledge for the public good."

The magazine also highlighted the strong links between Cornell's nanoscience programs and biological and agricultural research, as well as "a growing engagement with Weill Cornell Medical College."

SMALLTIMES

In peer rankings, Cornell was fourth in nano research, fifth in micro research and sixth in commercialization of both nano and micro sciences.

"Once again we've been appropriately recognized by both the national media and our peers for our excellence in nanoscience," said Joseph Burns, vice provost for physical sciences and engineering.

Burns also noted the recognition Cornell received for its nanoscience facilities, including the flagship Duffield Hall, which houses Cornell NanoScale Facility, a national user facility supported by the National Science Foundation.

"We are educating the next generation of scientists with the best faculty in superb facilities," Burns continued. "We firmly believe that our excellence in nanoscience will be an important component of economic growth in upstate New York in the next five years."

Malliaras wins NYAS Blavatnik Award for Young Scientists

By Anne Ju

The New York Academy of Sciences (NYAS) has given the Blavatnik Award for Young Scientists to George Malliaras, Cornell associate professor of materials science and engineering, and director of the CNF.

The prize, which included $25,000 to each winner, went to five scientists born on or after Jan. 1, 1965, who are "noteworthy and innovative researchers" from the states of New York, New Jersey and Connecticut, according to the NYAS. The awards honored accomplishments in the life, physical and social sciences as well as engineering, in both basic and applied research.

The winners were chosen from 14 finalists who represented a broad range of scientific disciplines and eight research institutions. They were selected by a panel of 43 judges who represented more than 25 academic and research institutions. Among this year's finalists were two other Cornell researchers: Antje Baeumner, associate professor of biological engineering; and Geoffrey Coates, the Betty R. Miller Professor of Chemistry. A Cornell alumna, Kathryn Uhrich, Ph.D. '92, professor of chemistry at Rutgers University, was also a finalist.

In addition to the Blavatnik Awards, the academy also honored Sanford I. Weill '55, a major Cornell benefactor, with the NYAS Economic Development for Science Award. The former chairman and CEO of Citigroup, Weill was called an "ardent supporter of scientific advancement through his generosity to Weill Cornell Medical College."

Beebe LAke, Cornell campus. Photographer unknown.

Defining the Interface between Nanoscience and Geology

Our 3rd Annual CNF Fall Modeling Workshop occurred on November 12-13th, with the theme "Defining the Interface between Nanoscience and Geology." At first glance, the time and length scales involved in the two fields are vastly different and the possibility of connections seems slim. However, nanoscale interactions and properties can translate to effects seen on much larger scales.

The workshop highlighted issues at the interface between nanoscience and geology. It also demonstrated nanoscale computational tools that could propel the next generation of geology researchers. The morning sessions consisted of lectures from leaders in the field who discussed current issues and the approaches available. Afternoon sessions provided hands-on sessions where participants got to work directly with these codes. In some cases, participants learned directly from the code's creator.

Presentations included:

- Current needs for modeling at small scales for geology (Jason Phipps-Morgan, Cornell)
- Predicting high pressure crystal structures in the Earth's interior with density functional theory (Richard Hennig, Cornell)
- Molecular dynamics approaches for biomineralization (John Harding, University of Sheffield)
- Water-mineral interactions on the nanoscale (Andrey Kalinichev, Michigan State University)
- An experimental perspective on biomineralization (Lara Estroff, Cornell)

The hands-on sessions included:

- An introduction to the DL-POLY Molecular Dynamics code (John Harding, University of Sheffield & Dr. William Smith, Daresbury Laboratory, UK)
- Using Quantum Espresso to predict high pressure crystal structures (Richard Hennig, Cornell)

The Fall Workshops are organized by Dr. Derek Stewart (stewart@cnf.cornell.edu) and this workshop was sponsored by the Kavli Institute.

The presentations and tutorials are available at www.cnf.cornell.edu/cnf_fallworkshop2007.html.

Cornell University
Kavli Institute at Cornell

The Cornell NanoScale Science & Technology Facility is a member of the National Nanotechnology Infrastructure Network and is supported by:

The National Science Foundation, the New York State Office of Science, Technology and Academic Research, Cornell University, Industry, & our Users.

New Tools and Capabilities at the CNF

CNF Plasma Etch Updates

We are pleased to announce several new process enhancements and developments in the CNF plasma etch area. On our recently purchased Trion Minilock III ICP etch system, we have completed a comprehensive study of chrome etching. By executing several experimental designs, we were able to determine the influence of major process parameters such as gas composition, pressure, ICP power, and electrode power on responses such as etch rate and selectivity to the resist mask. This optimized Cr etch process has been successfully applied to both microscale and nanoscale dimensions using conventional photolithography and electron beam lithography respectively.

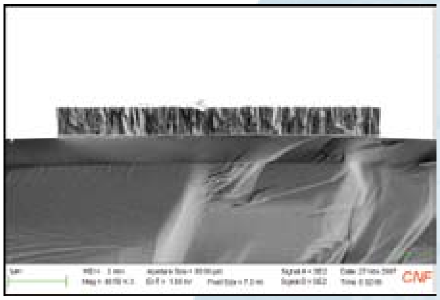


Figure 1: 200 nm Cr etched in the Trion Minilock III ICP.

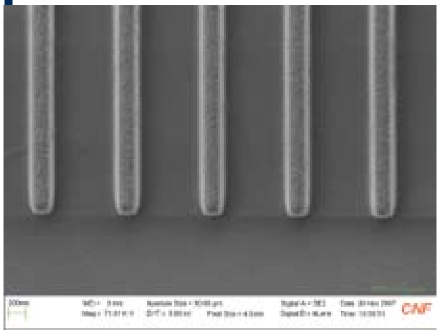


Figure 2: 20 nm Cr etched with negative ebeam resist.

In the near term, we plan to continue our investigation of glass etching in this system using the established Cr etch process, which will ultimately allow us to fabricate conventional and advanced photomasks. There are a number of process challenges associated with advanced photomask etching including critical dimension (CD) etch uniformity, minimized CD etch bias for both isolated and dense features, and zero defect generation.

As part of our ongoing cooperative development agreement with Oxford Instruments, we have recently investigated fused silica etching in the Oxford 100 380-ICP system. This system is dedicated to thick silicon oxide and glass etching and uses a variety of polymeric forming gases such as CHF_3, C_4F_8, and C_2F_6. These gases feature a low fluorine/carbon F/C ratio which is important in achieving high etch rates and selective etching to either underlying silicon or to a resist or metal masking layer. In addition, the high density plasma system allows us to independently control the ion fluxes and ion energies, enabling us to adjust DC bias levels for etch rate and selectivity maximization.

Our investigation was based on the optimized Cr etch process in the Trion Minilock III, which served as the etch mask, and included a rather thorough study and comparison of three etch chemistries using CHF_3, C_4F_8, and C_2F_6. The etch chemistries also included additive gases which influence the F/C ratio and the overall dynamics of the plasma. The design of experiments (DOE) studied the influence of input parameters such as gas composition, source and electrode powers, and pressure on etch rate, selectivity, and feature profile. The DOE yielded fused silica etch rates as high as 260 nm/min and selectivity to Cr as high as 300:1, along with anisotropic profiles of 90 ± 2°.

As evidenced in the accompanying SEM micrographs, the features are well defined and are free

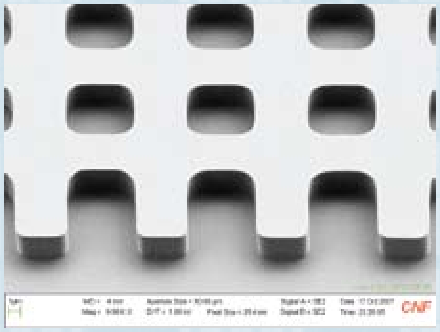


Figure 3: Fused silica etched to 2.4 µm depth with Cr mask using C_4F_8/O_2 chemistry in the Oxford 100 ICP .

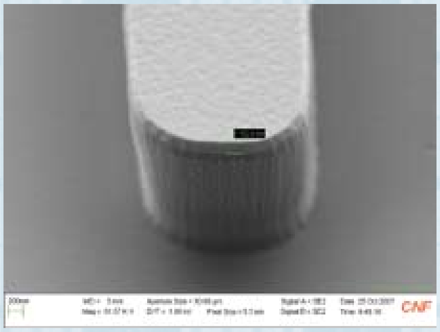


Figure 4: Fused silica etched to 2.4 µm depth with Cr mask using C_4F_8/O_2 chemistry in the Oxford 100 ICP

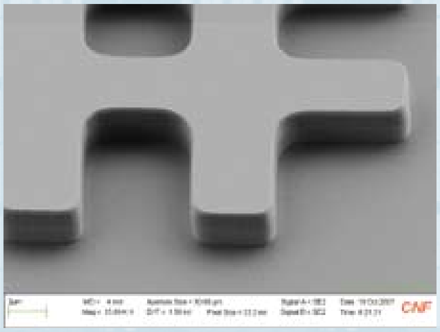


Figure 5: Fused silica etched to 2.1 µm depth with Cr mask using CHF_3/Ar chemistry in the Oxford 100 ICP.

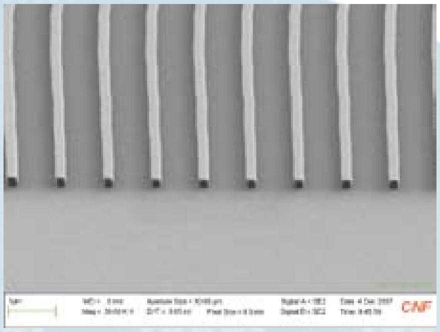


Figure 6: Electron beam lithography patterned fused silica etched to 260 nm with a 20 nm Cr mask in Oxford 100 using CHF_3/Ar chemistry.

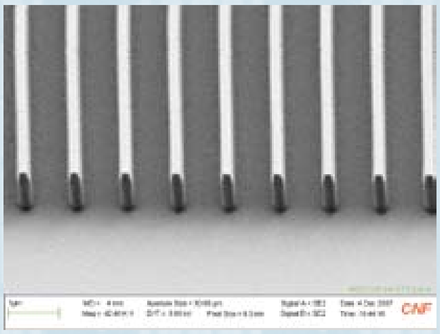


Figure 7: Electron beam lithography patterned fused silica etched to 650 nm with a 20 nm Cr mask in Oxford 100 using CHF_3/Ar chemistry.

of any etch artifacts. The etch parameters can also be applied to other substrate materials such as borofloat and pyrex glasses. These silica etch processes have many applications such as microfluidics, optical waveguides, optical gratings, and ultimately nanoimprint applications.

In addition, we have completed an in-depth investigation into polysilicon etching in our high density plasma Plasmatherm 770 system. This chlorine based ICP chamber is dedicated to single crystal and polysilicon etching using an SiO_2 hard mask. The study included undoped, N^+ doped, P^+doped polysilicon in both annealed and unannealed forms. Polysilicon etching has traditionally posed many challenges in the microelectronics industry due to the inherent grain size and structure, preferred orientation, and the influence of the dopants. Furthermore, as transistor dimensions continue to scale down with successive generations, linewidth control and selectivity to the ever thinning underlying gate oxide becomes crucial.

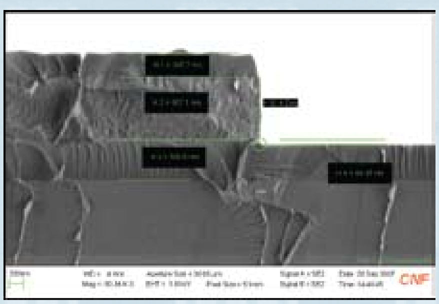


Figure 8: 1 µm P+ annealed polysilicon etched in PT770 ICP with GSI oxide mask.

This study demonstrates how etch parameters such as chemistry, power, and pressure influence and define the etch mechanisms of each type of polysilicon. Etch rates as high as 400 nm/min and selectivity as high as 28:1 to the masking and underlying oxide were achieved. The following SEM micrographs illustrate highly anisotropic profiles with a well defined termination to the underlying oxide. These etch results can be successfully applied to microelectronics and MEMS applications.

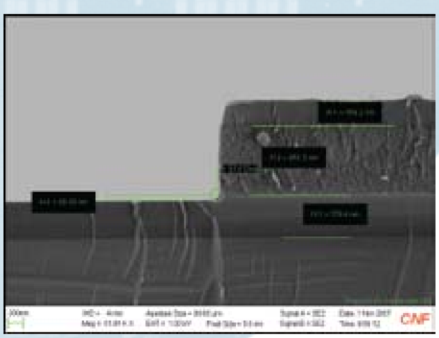


Figure 9: 1 µm P+ unannealed polysilicon etched in PT770 ICP with GSI oxide mask.

Likewise on the Plamatherm 770 silicon chamber, we conducted an extensive experimental design study of single crystal (100) silicon etching with depths of up to 10 μm. The objective was to examine and if necessary reformulate the chlorine chemistry and the etch parameters needed to successfully etch extended aspect ratio of both positive and negative type features. Extra motivation for this study was provided by a project with Columbia University. The following SEM micrograph shows well defined positive and negative features with smooth sidewalls and floors. These characteristics are especially essential for photonics applications.

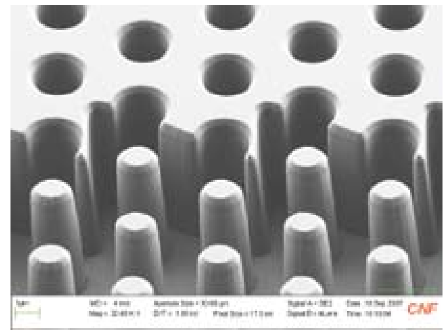


Figure 10: Single crystal Si etched to 5 µm depth in the PT770 with a thermal oxide mask.

For additional information on any of these process developments, contact Vince Genova at genova@cnf.cornell.edu.

Oxford 100

Trion Minilock III ICP

Mandy says: "I had a great time working at CNF. I would like to thank all my colleagues for a great atmosphere and the team spirit that made working fun. Starting in December, I will work as a postdoc with Prof. Shuler and Prof. Stokol here at Cornell. I will build on the existing micro cell culture analog device research and develop devices that are suitable to test contaminated environmental samples for their possible toxic effects on humans. I will also work with microfluidic devices that mimic parts of the human circulatory system. With this device, I hope I can uncover some of the mechanisms that enable breast cancer cells to break through this system and invade other organs."

Ana says: "I am going to York University, in Toronto, Ontario, Canada. as an Assistant Professor. I'll continue to do research on nanotechnology and more broadly on the practices of development and use of emergent technologies—I'll be teaching in the Department of Communication and Culture." (Ana will also be kept busy with little Mathias Barros Viseu Hessenbruch who will be two January 17th!)

SAVE THE DATE!

The Commercialization of Nanotechnology; An SBIR Workshop
Thursday, April 10th, 2008

The June CNF short course, Technology and Characterization at the Nanoscale
Starts Tuesday Evening,
June 3rd thru June 6th, 2008

The CNF Annual Meeting
Thursday, September 11th, 2008

Check the CNF web site often for details and updates.

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CNF Cornell NanoScale Science and Technology Facility

250 Duffield Hall
Cornell University
Ithaca NY 14853-2700
information@cnf.cornell.edu
607-255-2329