

The image shows a multi-level atrium of a modern building. A wide staircase with a grey stone-tiled wall is the central focus. The word "NanoMeter" is mounted on the wall in large, white, sans-serif letters. The ceiling has large, oval-shaped recessed lights. In the background, other levels of the building are visible, including a lounge area with orange chairs and a person walking. The overall atmosphere is bright and professional.

NanoMeter

**The newsletter of the
Cornell NanoScale Facility
Spring 2011 • Volume 20 • Issue 1**

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Welcome to the 2011 Spring Edition of the CNF NanoMeter

This issue will highlight some of the outstanding science and engineering being done by the Cornell NanoScale Science & Technology Facility (CNF) users. We also wish to bring you up to date about improvements in the laboratory.

Effective February 2011, we have merged cleanroom operations between the CNF and the Cornell Nanobiotechnology Center (NBTC) so that we will no longer maintain separate access controls for different parts of the cleanroom area. From now on, all CNF users will have access to all of the spaces in the Duffield Hall cleanroom, including the wing that previously had been set aside exclusively for NBTC tools. The staff of both CNF and NBTC are working together to maintain existing capabilities and obtain new tools. From the user's point of view, the most important aspect of these new arrangements is that there will be more available space to install some of the new tools detailed below.

One of our top priorities for new tools in the last two years has been to upgrade our capabilities for optical

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**Image of Duffield Hall (cover and background)
by Charles Harrington Photography**

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**The CNF is a member of the
National Nanotechnology Infrastructure Network**
(www.nnin.org)



**The CNF is supported by:
The National Science Foundation,
New York State Office of Science, Technology
and Academic Research, Cornell University,
Industry, and Our Users.**

**** <http://www.cnf.cornell.edu/> ** information@cnf.cornell.edu ****

lithography. We began in 2009 with the installation of an *ASML DUV (248 nm) Stepper*, capable of feature sizes less than 0.2 micron (μm). To take full advantage of the capabilities of this tool required also improved mask writing and more reproducible resist coating and baking. In 2010, we installed a *Heidelberg Mask Writer DWL2000* for higher-resolution (and much faster) mask making, and in May 2011, we will install a *SÜSS Gamma Coat and Wet Process System*.

As part of the arrangement for obtaining the SÜSS Gamma Coater, we have entered into a strategic collaboration with SÜSS MicroTec to perform research with several of their most advanced tools. With this agreement, we obtained the capability to perform *SÜSS Microoptic Illumination* in our *MA-6 Aligner*, along with a significant improvement in our technology for performing imprint lithography, with the *SÜSS Substrate Conformal Imprinting Lithography (SCIL)* process.

For fabricating microfluidic devices and a wide variety of other small parts, we are finding that a new *Universal Laser Systems VersaLASER CO₂ Laser Engraving & Cutting Tool* is quickly becoming one of our most popular tools. It can cut or etch patterns with features as narrow as 30-100 μm depending on the substrate, and it is particularly useful for making through-holes of any shape and dicing in many plastics, paper, rubber and heat-resistant glass. Users have also had success in fabricating gaskets and housings.

We have also very recently installed a *Hitachi FB-2000A Focused Ion Beam (FIB) System*. The new system produces an approximately 40 nanometer (nm) spot size gallium beam capable of milling a variety of metals, semiconductors and insulators, as well as depositing tungsten.

At the end of April, we installed a *ZYGO White Light Interferometer* that will modernize our optical profiling capability.

In the coming year, you can look forward to several additional improvements. We will be installing a new *AJA Sputter Deposition System* to expand our offering of materials available using at-the-ready targets, and to allow faster target changes compared to our existing sputter deposition system.

We are completing the installation of a *Primaxx Vapor Phase HF Etching Tool* to make nanoelectromechanical system (NEMs) devices and other released structures without the need for critical point drying. We are also working to develop reliable processes for *Growing Graphene and Carbon Nanotubes* by chemical vapor deposition onto wafers up to four inches in diameter.

Finally, we will be working on *improving our suite of optical microscopes, cameras, and software*, and will be adding more capacity in our photolithography areas for *spinning and baking SU8 and PDMS*.

Please note the dates for upcoming events below and on page 9. Also note that registration is now open for our June short course, page 14. Be sure to check our web site often for new updates, www.cnf.cornell.edu.

Most importantly, please continue to give us your recommendations for how to improve CNF.

Dan Ralph, Lester B. Knight Director, CNF
Don Tennant, CNF Director of Operations

SAVE THE DATE!

**The CNF Annual Meeting
will be held on Thursday,
September 15th, 2011.**

This event is an excellent opportunity for our colleagues to learn about the exciting research carried out by CNF users over the past year. There will be approximately 16 user presentations, plus our keynote speaker, Philip Kim, professor of physics at Columbia University.

**We look forward to
welcoming you to CNF!**

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

Single-Crystal Films Could Advance Solar Cells

By Bill Steele
Cornell Chronicle

Cornell researchers have developed a new method to create a patterned singlecrystal thin film of semiconductor material that could lead to more efficient photovoltaic cells and batteries.

The “holy grail” for such applications has been to create on a silicon base, or substrate, a film with a three dimensional (3-D) structure at the nanoscale, with the crystal lattice of the film aligned in the same direction (epitaxially) as in the substrate. Doing so is the culmination of years of research by Uli Wiesner, professor of materials science and engineering, into using polymer chemistry to create nanoscale self-assembling structures.

He and his colleagues reported the breakthrough in the October 8 issue of the journal *Science*. They used the new method to create a film with a raised texture, made up of tiny pillars just a few nanometers across. “Just the ability to make a single-crystal nanostructure has a lot of promise,” Wiesner said. “We combine that with the ability of organic polymer materials to self-assemble at the nanoscale into various structures that can be templated into the crystalline material.”

Wiesner’s research group previously used self-assembly techniques to create Grätzel solar cells, which use an organic dye sandwiched between two conductors. Arranging the conductors in a complex 3-D pattern creates more surface area to collect light and allows more efficient charge transport, Wiesner said.

Performance improves the most when the conducting materials are single crystals, Wiesner said. Most techniques for creating such films produce polycrystalline material — a collection of “grains” or small crystals bunched together at random — and grain boundaries retard the movement of electric charges, he explained.

Wiesner’s method uses block co-polymers to create porous templates into which a new material can flow and crystallize. A polymer consists of organic molecules that link into long chains to form a solid. A block copolymer is made by joining two different molecules at their ends. When they chain together and are mixed with metal oxides, one forms a nanoscale pattern of repeat-

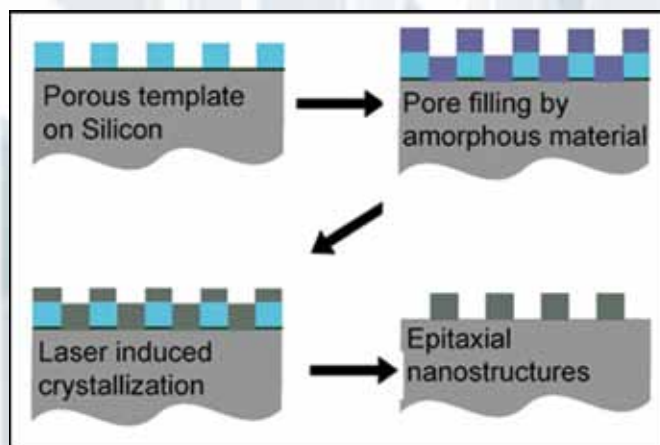


Figure 1: Amorphous silicon, deposited on a porous template, fills the empty spaces. Laser heating melts the deposit and the top few microns of the silicon substrate. In a few nanoseconds the melted silicon recrystallizes. The substrate acts as a seed crystal for the material above, causing it to crystallize with the same alignment. This makes it easier for electric charges to flow, making possible more efficient solar cells and batteries.

ing geometric shapes, while the other fills the space in between. Burning the polymer away leaves a porous metal oxide nanostructure that can act as a template.

Wiesner’s team created a template with hexagonal pores on a silicon single-crystal substrate and deposited films of amorphous silicon or nickel silicide over it. In collaboration with Mike Thompson, associate professor of materials science and engineering, they then heated the silicon surface with very short (nanosecond) laser pulses. This melted the newly deposited layer and the top few microns of the silicon substrate. After only a few tens of nanoseconds, the molten silicon recrystallized with the single crystal silicon substrate acting as a seed crystal to trigger crystallization in the deposited material above it, causing that crystal to line up epitaxially with the seed. The template is then dissolved away, leaving an array of hexagonal pillars about 30 nm across.

The team has made porous nanostructured films up to 100 nm thick with other complex shapes. In previous work Wiesner created lattices of cylinders, planes,

spheres and complex “gyroids” by varying the composition of co-polymers.

Other materials could be deposited, the researchers said. The goal here, they said, was to demonstrate the formation of film with the same material as the substrate (officially known as homoepitaxy) and with a different material (heteroepitaxy).

In a further proof-of-concept experiment, the researchers showed that the structured thin film could be arranged in micron-scale patterns, as might be necessary in designing an electronic circuit, by laying a mask over the surface before applying laser heating.

“We have essentially gotten to the holy grail,” Wiesner said. “It is not only a nanostructured single crystal, but it has an epitaxial relation to the substrate. There is no better control.”

The research was supported by the National Science Foundation, Department of Homeland Security and Cornell’s Energy Materials Center, funded by the U.S. Department of Energy, and performed in part at the Cornell NanoScale Science & Technology Facility.

Vibrating Nanorods Measure Thin Films for Microcircuits

By Bill Steele
Cornell Chronicle

A key step in many nanofabrication processes is to create thin films, sometimes only one molecule thick, by a method known as atomic layer deposition (ALD). Researchers at Cornell and Tel Aviv University have developed a new tool for nanofabricators to test the physical properties of such films.

Ultrathin films are increasingly important in constructing microcircuits. Their physical characteristics often determine their electronic behavior as well as their resistance to wear.

The researchers have shown that tiny resonant canti-

levers — silicon rods anchored at one end, like a tiny diving board — can determine the density of a film and its Young’s modulus, a measure of resistance to bending. The method offers several advantages over other methods of measuring these characteristics of thin films, the researchers said, and can be used by any researchers with access to nanofabrication capabilities comparable to those at the Cornell NanoScale Facility.

The work was reported in the August 15 issue of the *Journal of Applied Physics* by Cornell research associate Rob Ilic, Slava Krylov, senior lecturer at Tel Aviv University and former visiting professor at Cornell, and Harold Craighead, the C.W. Lake Jr. Professor of Engineering at Cornell. Cornell researchers have previously used tiny vibrating cantilevers just a few nanometers thick to detect the mass of objects as small as a virus. Just as a thick guitar string vibrates at a lower note than a thinner one, adding mass to a vibrating rod changes its frequency of vibration. Coating the rod with a thin film adds detectable mass, and from the mass and thickness of the film, density can be determined.

The film also changes the cantilever’s resistance to bending. To separate out this characteristic, the researchers compared in-plane (side to side) and out-of-plane (up and down) vibrations. The resistance to bending in different directions is noticeably different when the vibrating

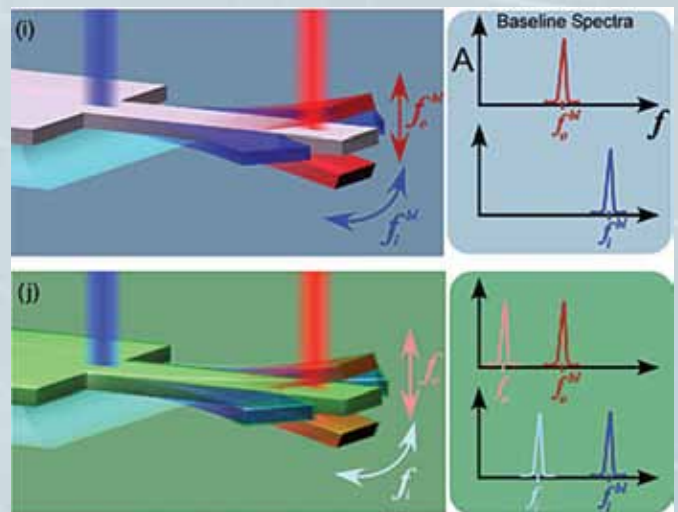


Figure 1: Schematic illustration of the measurement of in-plane and out-of-plane vibrational modes of a silicon cantilever. Modulated blue laser excites the NEMS structure and laser interferometry monitors the cantilever motion. Spectral characteristics of the in-plane (blue) and out-of-plane (red) modes change when a thin-film coating, shown in green, is applied.

rod is wide and thin. When the cross-section of the rod is square, there is no difference between up-and-down and side-to-side movement.

To test their idea, the researchers fabricated a variety of cantilevers 6-10 μm long, 45 nm thick and with widths varying from 45 nm to 1 μm . In various experiments, they applied films of aluminum, aluminum nitride and hafnium from 21.2 to 21.5 nm thick to the surface of the cantilevers.

A laser beam focused on the base of a cantilever supplies energy to set it vibrating, and another laser aimed at the end measures the vibration. Like a tuning fork, each rod has a resonant frequency at which it vibrates, and that depends on the dimensions and physical characteristics of the device. Comparing the resonant frequency and some of its harmonics before and after a film was applied enabled the researchers to calculate the density and Young's modulus of the film.

Over the course of many experiments, the calculations agreed well with theoretical predictions and characteristics of films measured by other methods. Some aspects of the method of fabricating the nanocantilevers could affect the results, the researchers found, but they said accuracy could be improved.

The work was supported by the Defense Advanced Projects Research Administration, the National Science Foundation and the state of New York, and was performed in part at the Cornell NanoScale Facility.

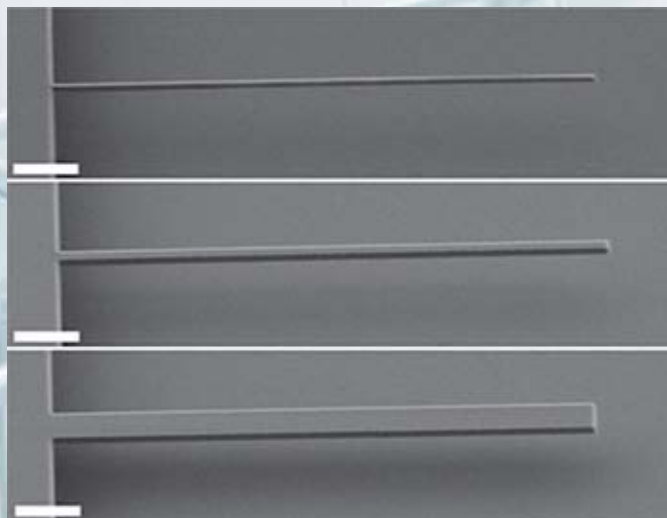
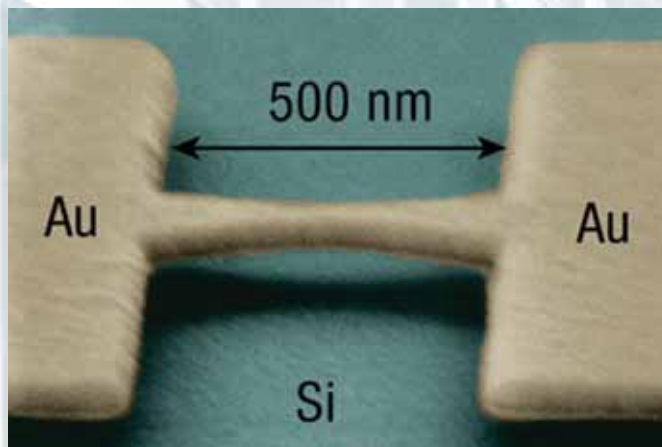


Figure 2: Scanning electron micrographs of silicon cantilevers 8 μm long and 75, 300 and 800 nm wide.

Stretching Single Molecules Allows Precision Studies of Interacting Electrons

By Anne Ju
Cornell Chronicle



Scientists everywhere are trying to study the electrical properties of single molecules. With controlled stretching of such molecules, Cornell researchers have demonstrated that single-molecule devices can serve as powerful new tools for fundamental science experiments. Their work has resulted in detailed tests of long-existing theories on how electrons interact at the nanoscale.

The work, led by professor of physics Dan Ralph, is published in the June 10 online edition of the journal *Science*. First author is Joshua Parks, a former graduate student in Ralph's lab.

The scientists studied particular cobalt-based molecules with so-called intrinsic spin — a quantized amount of angular momentum. Theories first postulated in the 1980s predicted that molecular spin would alter the interaction between electrons in the molecule and conduction electrons surrounding it, and that this interaction would determine how easily electrons flow through the molecule. Before now, these theories had not been tested in detail because of the difficulties involved in making devices with controlled spins.

Understanding single-molecule electronics requires expertise in both chemistry and physics, and Cornell's team has specialists in both.

“People know about high-spin molecules, but no one has been able to bring together the chemistry and physics to make controlled contact with these high-spin molecules,” Ralph said.

The researchers made their observations by stretching individual spin-containing molecules between two electrodes and analyzing their electrical properties. They watched electrons flow through the cobalt complex, cooled to extremely low temperatures, while slowly pulling on the ends to stretch it. At a particular point, it became more difficult to pass current through the molecule. The researchers had subtly changed the magnetic properties of the molecule by making it less symmetric.

After releasing the tension, the molecule returned to its original shape and began passing current more easily — thus showing the molecule had not been harmed. Measurements as a function of temperature, magnetic field and the extent of stretching gave the team new insights into exactly what is the influence of molecular spin on the electron interactions and electron flow.

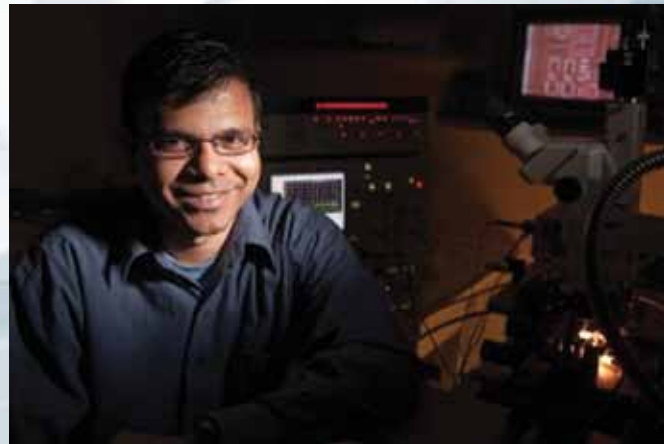
The effects of high spin on the electrical properties of nanoscale devices were entirely theoretical issues before the Cornell work, Ralph said. By making devices containing individual high-spin molecules and using stretching to control the spin, the Cornell team proved that such devices can serve as a powerful laboratory for addressing these fundamental scientific questions.

The study was funded primarily by the National Science Foundation through the Cornell Center for Materials Research, a Materials Research Science and Engineering Center. Research was performed at the CNF.

Rajeev Dokania: Fireflies Light up his Scholarship

by Jennifer Campbell

<http://ezramagazine.cornell.edu/Sidebar4.html>



Fireflies in Southeast Asia are able to blink in unison across entire tracts of forest — because each firefly watches its immediate neighbors light up, then adjusts to match them. ECE Ph.D. student Rajeev Dokania wants to apply this type of locally generated synchronicity to radios. Dokania came to Cornell in 2005 and received a prestigious Intel Foundation Ph.D. Fellowship, which funded technical and professional mentors in the company. Under the direction of his adviser, associate professor Alyssa Apsel, Dokania is part of a team that is pairing sensors with low-power radios, working in Apsel’s lab and the CNF.

When connected as a network, these radio nodes can detect data in their immediate environments and then synchronize their signals to share data across large areas. Apsel’s lab received more than \$650,000 from Lockheed Martin Corp. to support this work. The company hopes to apply the technology in areas such as border security, infrastructure monitoring and environmental sensing.

“Border intrusion motion detectors could be networked to communicate with each other about disturbances they detect,” thus forming a responsive line of security over long, unmanned distances, Dokania explains.

This type of network isn’t in place today because existing technology is bulky and saps batteries too quickly. “If radio nodes can harvest energy from the environment, such as solar energy, and the power requirement is low,” Dokania says, “then you can make the entire unit very small — something like one cubic centimeter.”

Donald Tennant, AVS Fellow

In the Fall of 2010, Donald Tennant, CNF Director of Operations, was elected as a “Fellow of the Society” — this American Vacuum Society (AVS) membership level is designated to recognize AVS members who have made outstanding, long-term scientific and technical contributions in research, engineering, technical advancement, academic education, or managerial leadership for at least ten years.

We congratulate Don on this prestigious recognition of his work.

CENTRAL NEW YORK

BUSINESS JOURNAL

MicroGen expects its first sales this year

BY KEVIN TAMPONE

JOURNAL STAFF

ITHACA — An Ithaca startup is on the cusp of commercializing a tiny power generator that can transform subtle vibrations into energy.

MicroGen Systems, Inc. expects a few hundred thousand dollars of revenue this year. Most of this year's sales will go to customers looking to test and evaluate the company's product.

Next year, the firm is projecting sales in the millions and expects its work force to climb to 15. MicroGen currently employs six people.

MicroGen's chip-sized device is aimed initially at wireless sensor networks. That means a network of sensors that use small radios to transmit their data to a remote location.

The market is a large one, MicroGen CEO David Hessler says.

"We'll be a very big company if we just can touch the things that are currently called wireless sensor networks," he notes.

Such small, radio-equipped sensors can monitor everything from the health of buildings and bridges to tire pressure and aircraft components. Initially, MicroGen is focusing on buildings and equipment within buildings like heating and cooling systems.

The company is also concentrating on civil infrastructure like bridges and military applications.

All of the sensors used in wireless networks need a battery to work, Hessler explains. MicroGen provides a way to recharge those batteries and eliminates the need for constant manual changing.

"People aren't deploying those [sensors] as fast as they should because they can't figure out what to do with the battery," Hessler says. "People that want to deploy these, if they're going to do it, their mantra is set it and forget. They want to place it and leave it alone."

MicroGen's customers will include firms that create the sensors, batteries, and networks and their components as



PHOTO COURTESY OF MICROGEN SYSTEMS, INC.

A MicroGen employee works on a project. The company expects a few hundred thousand dollars of revenue this year.

well as larger companies that provide entire monitoring systems.

The company's device provides an ideal solution for wireless sensor networks because it doesn't require much motion to generate power. The vibrations from a standard fish pump are enough, says Robert Andosca, MicroGen founder, president, and chief technology officer.

Andosca first began developing the MicroGen device while in graduate school at the University of Vermont.

He says companies developing the batteries MicroGen aims to recharge have invented something akin to the Model T Ford.

"It's an advanced thin film battery and it's pretty cool and everything," Andosca says. "But once it runs out of juice, once the tank is empty, it's empty. We now have invented the gas station."

MicroGen's main base of operations and headquarters is in Ithaca at the Cornell Business and Technology Park. The company has done much of its research and development at Cornell University's NanoScale Science and Technology Facility.

MicroGen was also one of the first companies admitted to the Syracuse Technology Garden's Clean Tech Center and has an office there. The firm drew some of its first investors from the Syracuse area, says Hessler, who is based at High Tech Rochester where he is also an entrepreneur in residence.

MicroGen is in the midst of raising its first significant capital. It expects to close on \$1.6 million in funding by May.

To date, the firm has been funded by angel investors and angel groups, along with the New York State Energy Research and Development Authority.

The potential for MicroGen's technology is broad, company leaders say.

Recharge a cell phone by walking? It's difficult, but possible. Can vibrations culled from a human body power a pacemaker? Perhaps.

Ultimately, any place there's a battery is a potential target market, Hessler says. MicroGen's device could even replace batteries in some applications in the future.

Contact **Tampone** at
ktampone@cnybj.com

CNF Staff Member, Derek Stewart, Wins NSF Grant

Derek Stewart (CNF Senior Research Associate) has won a three year collaborative research grant (\$199,351) from the National Science Foundation (NSF) to develop a new theoretical approach to calculate lattice thermal conductivity in crystalline and alloyed materials from first principles. Derek will be working collaboratively with Prof. David Broido (Physics, Boston College) who received separate NSF funding for this research.

Accurate modeling of thermal conductivity is essential in numerous fields including thermoelectrics, microelectronics cooling, and even heat transfer in planetary cores.

Current theories of lattice thermal conductivity are usually based on either highly parameterized relaxation time approximations or on classical molecular dynamics calculations with empirical potentials.



The new first principles theory Derek is developing has no adjustable parameters and uses density functional perturbation theory to calculate the quantum mechanical phonon scattering processes directly.

It should provide new predictive power to support ongoing and future experimental studies of thermal transport in materials and also help in the design of new materials for thermal applications. The project will

focus on the thermal conductivity of nanoparticle-in-alloy-structures, lead chalcogenides, and I-V-VI2 semiconductors.

The computational tools developed during this project will also be incorporated into the publicly available suite of simulation tools available at the Cornell NanoScale Science and Technology Facility.

CNF EVENT • Registration is Open! • CNF EVENT

CNF Short Course: Technology & Characterization at the Nanoscale

(CNF TCN, http://www.cnf.cornell.edu/cnf_junetcn.html)

Tuesday-Friday, June 7-10, 2011

This intensive 3.5 day short course, the CNF TCN, offered by the Cornell NanoScale Science & Technology Facility, combines lectures and laboratory demonstrations designed to impart a broad understanding of the science and technology required to undertake research in nanoscience. Attendance is open to the general scientific community, but class size is limited to 30 participants — so register online soon!





CNF EVENT • FIRST LEGO® League Expo • CNF EVENT

The Cornell NanoScale Facility hosted our 5th Annual Junior FIRST LEGO League Expo (Jr.FLL) on Saturday, January 29th. Nine teams with over 50 kids total, presented their work on a LEGO model depicting an aspect of this year's "Body Forward" Challenge. The "Body Forward" Challenge asked the kids to think about the human body, and the types of professions and devices used to help with injuries or disease. Teams can in for the Expo from as far away as Rochester, NY to present their work. The models varied from lasers to correct fast beating hearts to syringes that the kids were all too familiar with from the doctors' offices. The Ithaca Sciencenter assisted with the event by providing a DNA precipitation activity and the ever popular Stomp Rockets! This year the event was underwritten by the generous support of the Shell Corporation. Everyone had a good time and the CNF is looking forward to hosting again next winter.

CNF EVENT • 2011 NanoDays • CNF EVENT

For two days in early April, CNF staff and researchers participated in the national festival, NanoDays (<http://www.nisenet.org/nanodays>). Together with a whole lot of kids, we built molecules, tested the theories of magnetism, studied very tiny images, and made batteries out of fruits and hamburgers! Children of all ages had a great time!



CNF EVENT • CNF Annual Meeting • CNF EVENT

The 2010 CNF Annual Meeting was held on Thursday, September 16th, on Cornell University campus. Over 200 people attended this day-long event full of presentations and posters, research cross-pollination and corporate-sponsored awards.

The CNF was pleased to have twenty-one corporate sponsors! (Their logos are on the right.) We thank them all for their support of our work.

Because of our corporate generosity, we were able to give three “best talk” awards and three “best poster” awards — see the photograph of our winners below, third row down, second from the right.

In addition, we bestowed the Nellie Yeh-Poh Whetten Memorial Award upon two deserving young women — see their photograph below, bottom left, and read about their work on the next four pages.

Our next annual meeting will be held on Thursday, September 15th, 2011 — and it isn't too soon to save the date for our 35th Anniversary Celebration, which will be held Wednesday-Friday, July 11-13, 2012!

We hope you'll join us for these events.



Charles Harrington
Photography

2010 CNF Whetten Memorial Award Winner Profile: Ching-Ping Janet Shen

Ching-Ping Janet Shen is a fifth year graduate student in the Department of Biomedical Engineering (BME) at Cornell and is one of the two 2010 recipients of the CNF Nellie Yeh-Poh Lin Whetten Award. The Whetten Award recognizes an outstanding female graduate student who shows spirit and commitment to professional excellence, as well as professional and personal courtesy.

Janet received her bachelor's degree in Mechanical Engineering and Business, Economics, and Management at the California Institute of Technology in Pasadena, California, in 2006. At Caltech, she conducted research on the feasibility of using shape memory alloys as microactuators in micro-electro-mechanical systems (MEMS) devices. In the fall of 2006, she joined the Ph.D. program at Cornell, where she currently is a member of Professor Amit Lal's SonicMEMS research group in the School of Electrical and Computer Engineering (ECE).

Janet's main research focus is in developing wireless silicon (Si)-tissue interfaces to study neural and cardiac systems and properties. Bioelectrical interfaces can potentially be used to treat and understand a variety of disorders, including cardiac arrhythmias, epilepsy, and Parkinson's disease. Additionally, an active research area in the longer term is developing bio-interfaces to create neural interfaces to assist in sensory and motor functions.

Janet's research has focused on development of systems for biosensing applications. These involve studying the onset of ventricular fibrillation in 3D throughout heart tissue, developing neural interface quantification tools, and investigating the feasibility of a hybrid insect silicon olfactory sensor.

In the first research area, Janet has worked on development of wirelessly coupled ultrasonically inserted silicon probes to study cardiac arrhythmia onset,

as shown in Figure 1. Sudden cardiac death linked to ventricular fibrillation (VF) is one of the leading causes of death in the United States, but the mechanisms leading to its onset are not fully understood. Current models examine the 2D onset and propagation of action potentials and propose a cardiac alternans onset model, with alternating long and short action potentials which can bring about VF. However, the ventricles are on the order of 5-10 mm thick, and current models lack information about the propagation within this thickness.

Janet's research focuses on developing a wirelessly coupled ultrasonically inserted silicon system to allow study of VF through the 3D thickness of ventricles, and map the fundamental restitution relations governing signal propagation through the tissue, as shown in Figure 2. By resonating the silicon ultrasonic structures at their longitudinal resonances using the piezoelectric material lead zirconate titanate (PZT), the tissue reaction forces to probe insertion are reduced, allowing the silicon probes to penetrate the tough cardiac tissue and avoid silicon fracture.

Janet has developed a wireless transmission system with the ultrasonic probes for mapping the electrical activity.

Additionally, Janet is developing tools to allow investigation of mechanical-electrical coupling through VF onset, with integration of polysilicon strain gauges in cardiac probes. The ultrasonic probe with integrated sensors allows investigation of mechanical-electrical coupling during normal activity and under conditions associated with VF onset. The unique force reduction properties of the ultrasonically driven system provide advantages not only in avoiding silicon fracture, but also in potentially minimizing tissue damage and reactive properties ideal for long term bio-interfaces.



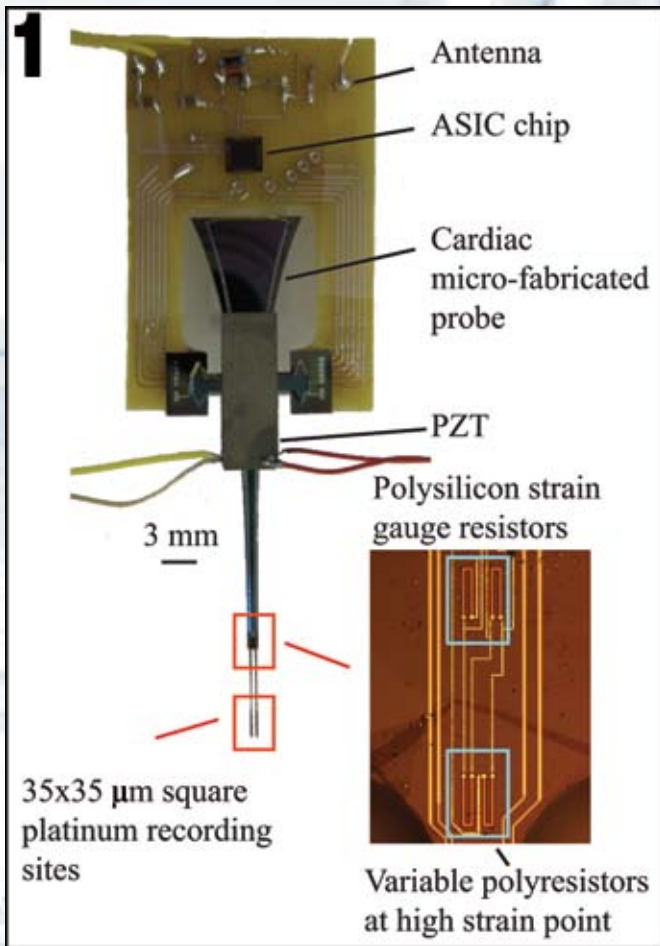


Figure 1, left: Ultrasonically actuated silicon probes with integrated strain gauges and wireless transmission application specific integrated circuit (ASIC). The probes have platinum electrical recording sites distributed along the length of the probes.

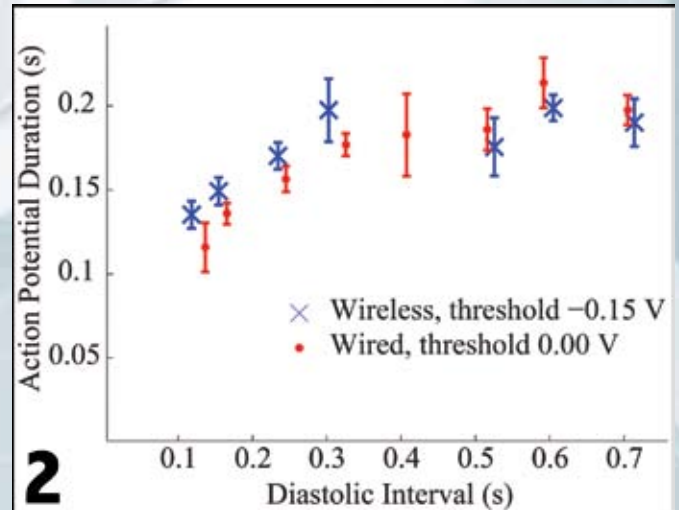


Figure 2, above: Measured cardiac restitution curves from canine ventricle for wired and wirelessly transmitted data recorded using ultrasonically inserted silicon probes.

Janet is developing a miniaturized ultrasonically actuated probe system with integrated sensors for neural interface recording and quantification. Development and fabrication of the ultrasonically actuated probes has been conducted in the Cornell NanoScale Facility (CNF).

In the second research area, Janet has developed an implantable neural probe system which can be used as an olfactory sensor to detect insect neuronal responses to olfactory components in its environment. The basis of the system involves a silicon neural probe with platinum recording sites developed and fabricated in the CNF.

Insects have sensor abilities developed over billions of years of evolution, and the potential to tap into these for use as environmental sensors is promising. By integrating

the silicon devices during an early stage of development of the insects, during metamorphosis, the devices are able to be well integrated into the insects to serve as long term implants without affecting the lifespan of the insects. The sensor interface can distinguish tobacco and pheromone olfactory components in the insect's environment.

Outside of her Ph.D. research, Janet has been involved as a Cornell NanoScale Facility Fellow for the CNF from 2010-2011. During this time, she worked characterizing UV cure processes for photoresist to withstand ion implantation.

She has also been involved in Expanding Your Horizons (EYH) as a session co-organizer on fluids and microfluidics activities for middle and high school girls.

2010 CNF Whetten Memorial Award Winner Profile: Christine Tan Cipriany

Christine Tan (Cipriany), a graduate student at the Department of Biomedical Engineering at Cornell University, is one of the recipients of the CNF Nellie Yeh-Poh Lin Whetten Award in 2010. This award recognizes an outstanding female graduate student for her scientific excellence, interdisciplinary collaboration, professional and personal courtesy, as well as exuberance for life.

A native of Singapore, Christine received her B.Eng degree in Biomedical Engineering from Imperial College London in 2005. Soon after, she arrived in Ithaca and joined the laboratory of Professor Harold Craighead — a research dream come true. While in the Craighead group, Christine developed several new and interdisciplinary approaches for nano- and micropatterning biological surfaces using a unique family of polymer, parylene.

Spatial manipulation of biomolecules and cells on a surface with nano- and micrometer scale precision is important in engineering biological microenvironments for tissue engineering, micro total analysis systems (biosensors, microfluidics and microarrays), and fundamental biophysical studies. Despite many advances being made in the surface patterning technologies and the patterning resolution continually being challenged, the fundamental needs of surface patterning have only been partially met. Christine's research attempts to bridge the gap in current surface patterning techniques.

Parylene Peel-Off is a simple and adaptable tool, widely used



Christine Tan (right) with her husband Benjamin Cipriany (left).

to improve current strategies for micropatterning biological environments and chemically sensitive organic materials. For biological microarray applications, parylene-C templates have been used as stencils for printing nano- and microscale regions of nucleic acids, proteins, lipids and cells.

Afterwards, the parylene template can be easily “peeled off” to yield arrays of highly uniform biomolecular features in a large area format. The advantages of parylene-C stencils include the amenability

fabrication using standard photolithography processes, biocompatibility, and the absence of polymer swelling in aqueous biological environments thus preserving the fidelity of patterned array features.

In collaboration with Professor Claudia Fischbach's group, Christine pioneered the use of parylene-C stencils for cancer studies. Arrays of fibronectin features, a protein that promoted cell adhesion, were first patterned. By varying the spatial dimension of the fibronectin pads (either 20 x 20 μm squares or 40 x 40 μm squares), highly uniform large-area arrays of single cancer cells or cancer cell clusters can be patterned (Figure 1). This allowed

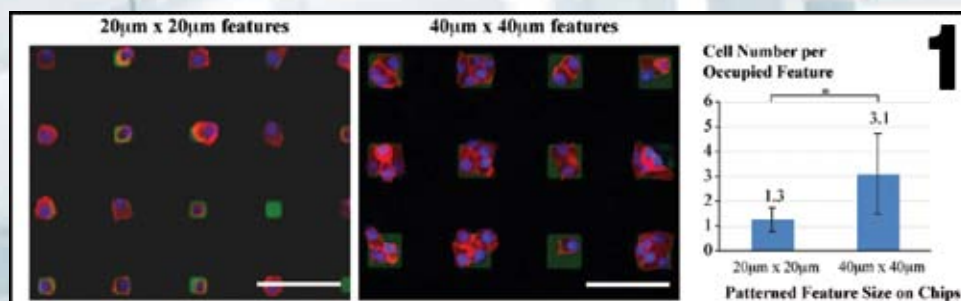


Figure 1: Arrays of single cancer cells and cancer cell clusters cultured on parylene-based patterned surfaces of 20 μm x 20 μm (A, left) and 40 μm x 40 μm (A, right) fibronectin features, respectively. Cancer cells (nuclei [DAPI, blue], cytoskeleton [phalloidin, red]) and patterned fibronectin (anti-human fibronectin, green) are fluorescently stained. Average number of oral cancer cells per fibronectin feature on the different chips was quantified by image analysis (* $p < 0.01$).

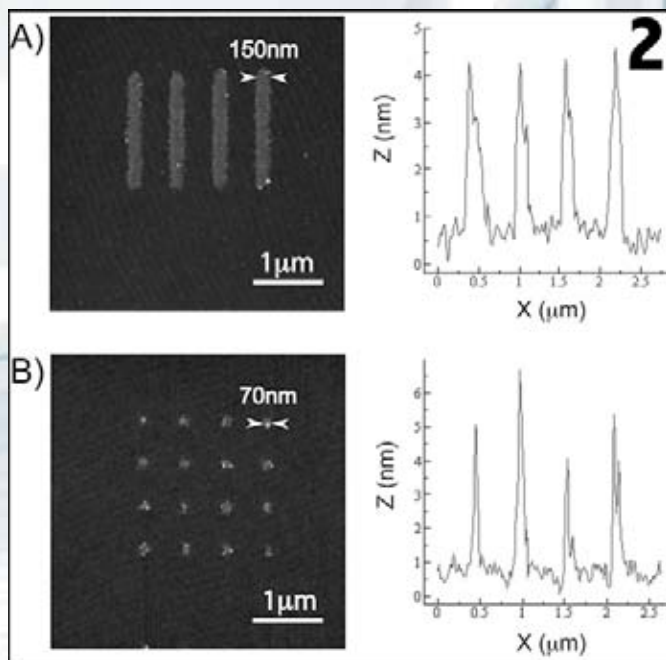


Figure 2: Smallest patterning resolution using parylene-C stencils. AFM image showing nanoarrays of patterned 90 nm fibronectin spots. The heights of the patterned fibronectin features were relatively uniform at 4-5 nm.

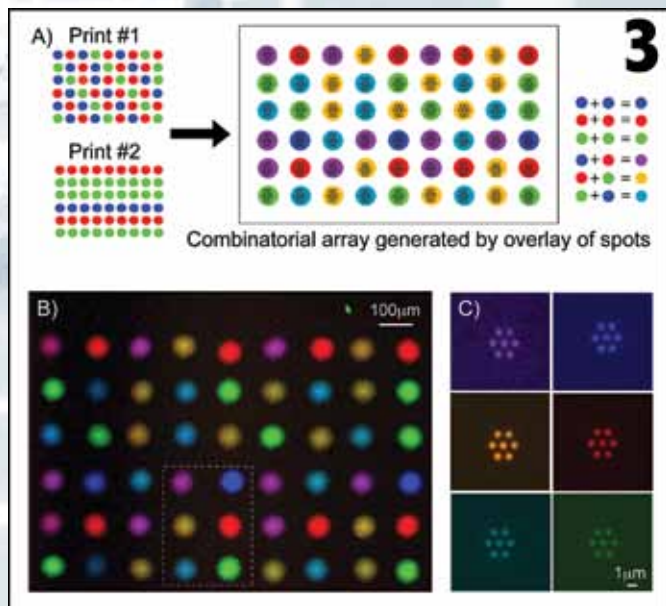


Figure 3: Combinatorial biological nanoarrays generated by parylene stencils combined with inkjet printing. (A) Schematic diagram showing the process of superimposing a second inkjet print-run immediately over the first print to generate six different combinations of antibodies from an initial pool of three separate antibodies. (B) Pseudo-color merged fluorescence image showing the combinatorial array that can be inkjet printed onto the parylene template. (C) Antibodies nanoarrays of six different biomolecular combinations were generated after parylene stencil peel-off, corresponding to the spots demarcated within the boxed region in (B).

spatiotemporally controlling cancer cell-cell interactions, and elucidated their role in regulating angiogenesis, a precursor to cancer progression.

Utilizing the advanced tools and staff nanofabrication expertise at the CNF, Christine demonstrated a new nanofabrication process flow to create parylene-C stencils with nanoscale openings. Using these stencils, protein arrays with array feature sizes down to 90 nm were patterned (Figure 2). In collaboration with Professor David Lin, she further combined these parylene stencils with inkjet printing, to rapidly generate multi-component, combinatorial protein nanoarrays with high throughput (Figure 3).

It is anticipated that Christine's work will be useful for enabling high-resolution studies of subcellular biological processes, integrating biochemical functionalities with miniaturized sensors, and engineering cellular and tissue microenvironments. Beyond basic science, Christine believes that the parylene surface patterning technology can be a useful tool to pattern chemically sensitive materials that are difficult to manipulate on the nano-scale, improve drug screening, and enable current inkjet printing technologies to extend their resolution to the sub-micrometer scale.

Outside the walls of the laboratory, Christine enjoys writing and volunteer work. Her poems, essays and sermons have emerged in various forms, such as Cornell-based publications, blogs, and Sunday services at the Protestant Cooperative Ministry. She is passionate about making science accessible to high school and undergraduate students, and encouraging more women to be interested in science and engineering. Christine has also instructed courses on nanobiotechnology at Dryden High School and Cornell Nanobiotechnology Center events. She is grateful for the rewarding academic experience at Cornell and also the supportive community of CNF staff and users.

Christine is currently a Process Integration Senior Engineer in the MEMS division at GLOBALFOUNDRIES. Her responsibilities include seamlessly integrating MEMS customers' requirements with the CMOS process flows at the foundry.

NNIN & Social and Ethical Issues of Nanotechnology

As with any new and emerging technology, societal and ethical issues (SEI) play an important part in their development. Nanotechnology is no different. To address these issues, NNIN seeks to stimulate reflection and research on SEI related to nanotechnology throughout the breadth of network activities.

One way that it does this is through the SEI orientation for new users of NNIN labs. As part of the new user orientation, participants engage in about a 30 minute discussion of SEI led by a lab staff member. Feedback from users who have completed the SEI orientation suggest that most found the discussions engaging and worth their time. Many also said that the SEI orientation stimulated them to consider SEI related to their own research.

Feel free to visit the NNIN SEI portal, <http://sei.nnin.org/>, to learn more. In particular, a series of SEI posters, right, has been created, and they are available for free following the instructions at http://sei.nnin.org/sei_posters.html

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The 2010 NNIN REU Program

During the summer of 2010; 80 students participated in our Research Experience for Undergraduates (REU) Program, 18 students from the 2009 NNIN REU Program participated in our International Research Experience for Undergraduates (iREU) Program, and five graduate students from Japan participated in our International Research Experience for Graduates (iREG) Program.

We work diligently to ensure that all three of these programs result in very substantial experiences by focusing on advanced research and knowledge, seeking

strong mentors and staff support, exposing our interns to a professional research environment, and having high expectations built into the research projects and the convocation.

In addition, at each site, the exposure to a wider variety of research conducted by peers and other users across diverse disciplines of science and engineering within the unifying facilities, also provides significant complementary experience.

My thanks to the staff, the graduate student mentors and the faculty for their participation and involvement. Particular thanks are due to Melanie-Claire Mallison and Lynn Rathbun at Cornell, and Nancy Healy at Georgia Institute of Technology for their contributions in organizing the logistics of these programs, and many thanks to Becky von Dissen and Jim Marti for organizing the network-wide convocation at the University of Minnesota-Twin Cities.

I wish all our program participants the best wishes for future technical careers; NNIN hopes you will build on this summer's experience and looks forward to hearing from you on your future successes!

Prof. Sandip Tiwari, Director, NNIN
st222@cornell.edu



The 2010 NNIN REU Interns at Cornell see a bright future ahead, while Melanie-Claire Mallison reminds them all to keep in touch!

Universal Laser Systems 50-Watt VersaLASER VLS 3.50

Exciting laser cutting and engraving micromachining capabilities are available using the Universal Laser Systems 50-Watt VersaLASER VLS 3.50. The infrared carbon dioxide (CO_2) laser vaporizes and easily cuts or etches polymers and glass, and marks many metals or silicon wafers using pigmented metal marking compound. Unfortunately, the laser won't cut bare silicon wafers.

To date, the tool has proven most useful in cutting, engraving and dicing heat-resistant glass and polymers (acrylic, Kapton[®] and Delrin[®] and rubber gasket materials, for example). The processes for cutting quartz, fused silica and borosilicate wafers from the CNF stock room have recently been optimized. Regularly-shaped features including rectangles and curved channels as small as 200 μm wide can be cut in a matter of seconds! Contact Beth Rhoades for testing your material and features.

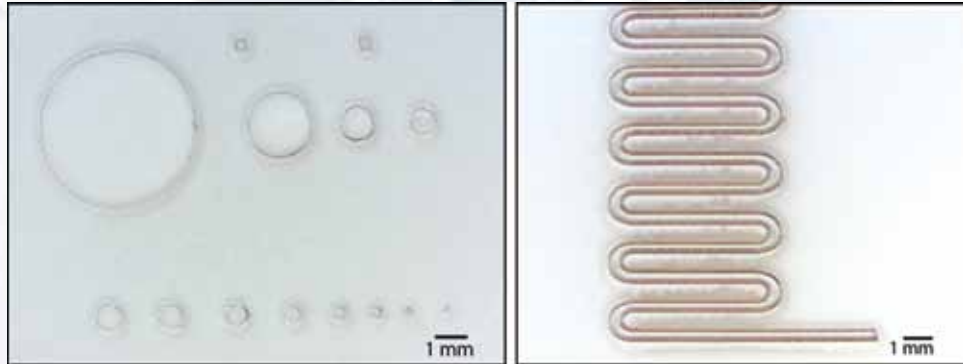
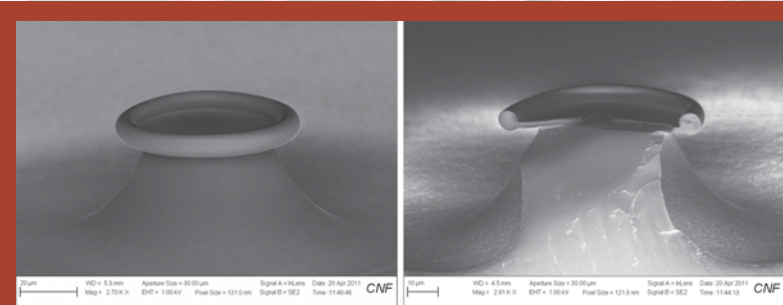


Figure 1, left: Round and square through holes were cut into fused silica (500 μm thickness) with diameters between 100-5000 μm . Figure 2, right: A serpentine channel was scribed partway through fused silica (500 μm).



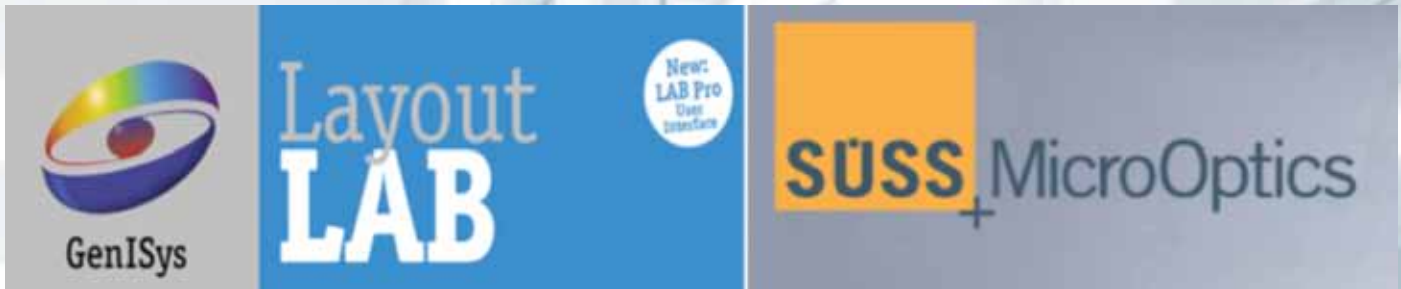
The silica microtoroid shown here is a high quality factor optical resonator. When laser light is coupled into the toroidal rim, only certain wavelengths can circulate around the circumference, and the extremely smooth side-walls lead to very narrow optical resonances. Silica microtoroids have the highest quality factor of any on-chip photonic devices to date, allowing for extremely high-precision sensing and signal processing applications.

This microtoroid is made by defining a 100 micron diameter silica disk on top of silicon, undercutting the rim of the disk with a xenon difluoride isotropic etch, and partially melting the overhanging rim with CNF's VersaLaser 50 watt CO_2 laser tool. The infrared laser light is absorbed by the silica but passes directly through the silicon, melting the disk edges without affecting the underlying substrate. The cross-section view (right) shows how the edge of the disk melts into a near-perfect toroid, connected to the underlying Si by the unmelted portion of the disk.



Beth brought the VersaLASER to the CNF Annual Meeting and our guest Lena took full advantage of the demonstration! Photographs by Charles Harrington Photography • Used with permission from Lena's parents.





Layout LAB is a software module from GenISys, GmbH that has recently been installed at CNF. It provides full 3D simulation for proximity lithography processes, with mask aligners or other proximity exposure tools that are widely used for Flat Panel Displays, MEMS, 3D integration and optical/electronic devices. Simulation shortens the development cycle, enables optical proximity correction (OPC) and design for manufacturability (DFM), as well as saves time on layout and process development before producing masks and running experiments.

Benefits of Layout LAB include:

- Models any proximity lithography equipment (mask-aligner, contact-printer, proximity-printer)
- Broadband spectrum, collimation angle and complex source shapes, large gaps
- Arbitrary mask layouts, including gray tone and phase shift
- Any substrate material, coatings, thick resist, topography
- Fast and accurate calculation of aerial image, bulk image in the resist, PAC concentrations, photoresist profiles based on threshold or 3D Mack development model
- Fast and flexible 1D, 2D and 3D visualization, metrology and matrix viewing

The primary application of Layout Lab at CNF is source mask optimization (SMO) on the SÜSS MicroTec MA-6 mask aligner. SMO is a photolithography enhancement technique commonly used in projection lithography to compensate for image errors due to aberrations, diffraction or process effects. Simulating an exposure in Layout LAB prior to entering the Nanofab will allow one to examine pattern fidelity as a function of resist type, exposure conditions and illumination filter plates.

On the wafer processing side, the primary goals are to improve CD control as well as correct image or process errors in both contact and proximity lithography.

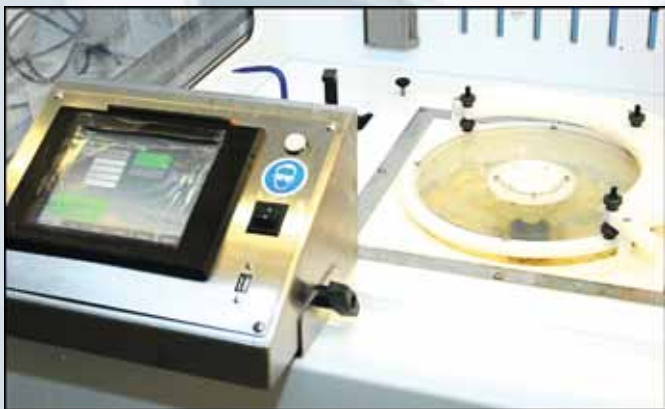
Exchangeable illumination filter plates (IFP) on the MA-6 allow one to precisely shape the illumination light for optimizing a particular geometry on-wafer. A quick and easy changeover between different illumination settings (including all previous SÜSS illumination optics) enables highest process flexibility. Customized Illumination (IFP-Design) in combination with optical proximity correction (OPC) allows one to pre-compensate print errors such as corner rounding and line edge shortening.

Please contact Garry Bordonaro (bordonaro@cnf.cornell.edu) or Noah Clay (clay@cnf.cornell.edu) for information about SMO and the use of Layout LAB.

About GenISys, GmbH: Based in Munich, Germany, GenISys develops, markets and supports flexible, high-performance software solutions for micro- and nano fabrication processes. <http://www.genisys-gmbh.com>.

About SÜSS MicroTec, GmbH: Based in Garching, Germany, SÜSS MicroTec is a leading suppliers of equipment and process solutions for microstructuring in the semiconductor industry. www.suss.com.





Brewer Science Spinners

Spinners are a fundamental part of lithography. Unfortunately over the last year the e-beam lithography spinners were becoming more and more unreliable. This was especially apparent when spinning small samples — which would often times lose vacuum and fly into the spinner bowl. We have now purchased two new spinners from Brewer Science to improve spinning reliability. These new spinners are also the same models used in the photolithography area, making the training process easier for users doing both e-beam and photolithography.

Hitachi FB-2000

For several years, the CNF had a FEI 611 focused ion beam. Although it was a capable tool in its day, we were no longer able to find parts and service for such an old tool. As a result, it was mostly inoperable for the last two years of its life.

We recently have been able to acquire a relatively new Hitachi FB-2000 being sold by Corning, Inc. The tool is single beam and has tungsten deposition capability. And, most importantly, we will be able

to service the tool for many years to come.

This new tool also has a smaller beam than the old FEI and gives much smoother sidewall profiles after cutting. It is now installed and available for training.



New Primaxx Vapor Hydrofluoric Acid Etcher

The CNF has recently installed a Primaxx μ Etch system for isotropic vapor HF etching of silicon oxide. This dry process allows for single step releases of MEMS structures without stiction or use of critical point drying. Additionally, the dry plasma-free process allows for etching without attacking other materials that are commonly etched in aqueous HF, such as aluminum. Another difference is that unlike aqueous HF, silicon nitride and photoresist do not work well for this process, leading to some masking challenges. The single wafer system utilizes a gas cylinder of anhydrous hydrogen fluoride gas with ethanol vapor at subatmospheric pressures (~1/5 atm) to achieve undercut rates as high as 0.25 μm / minute. The processing time is highly dependent on the geometry of the structure being released, but typical process times are an hour or two per wafer. Please see the CNF web site for more information or to contact staff with further questions.

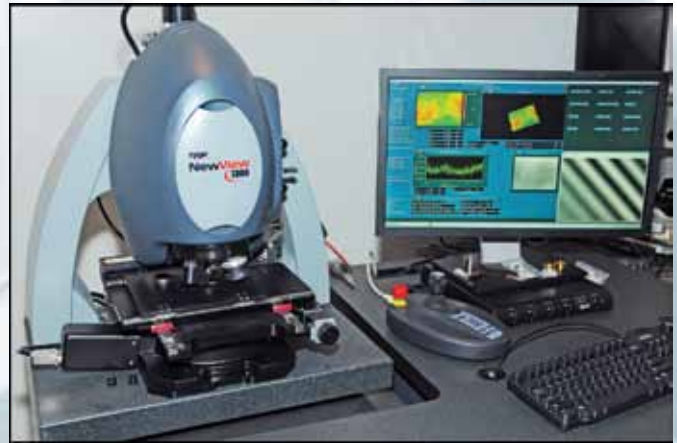


Zygo Newview 7300 Optical Profilometer

For several years, the CNF has had a Wyko HD-3300 optical profilometer that served the community well. However, this tool was purchased used and always had several limitations in its capability. The CNF has now acquired a new Zygo NewView 7300.

This is a state-of-the-art optical profilometer with additional capabilities not available on our older Wyko. The Zygo will scan at a maximum rate of 135 $\mu\text{m}/\text{sec}$ and has a maximum scan length of up to 20 mm. The stage is completely automated, allowing stitching of multiple fields. In this way, large samples that are outside the field of view of the objective can be “stitched” together. This effectively means that any size sample can be scanned.

Additionally, this tool also has the ability to take movies of moving objects — like oscillators and MEMs devices. This is done by matching the driving frequency of the device with a strobing option on the illumination. Multiple images are then combined to form a movie of the



device under test. Transparent stacks of materials can also be scanned more accurately now by inputting their refractive index before the scan.

The NewView 7300 is a great addition to the metrology capabilities at the CNF.

SÜSS MicroTec Gamma Wafer Coater/Developer

The CNF moved a new SÜSS MicroTec Gamma wafer coater/developer tool into the clean room this week. Installation is expected to be completed by the first week of June.

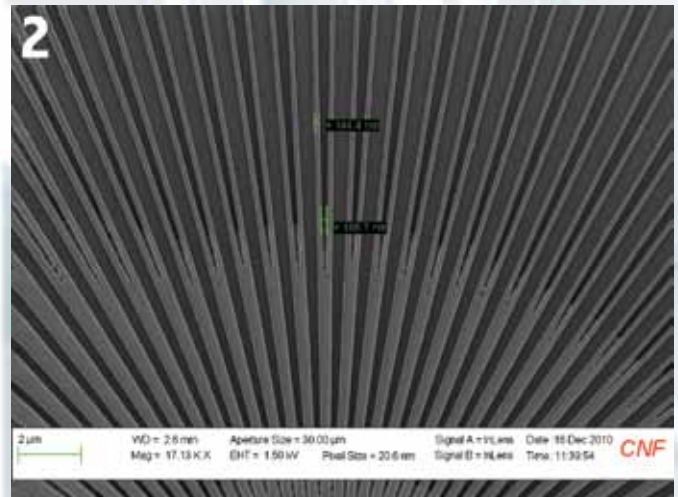
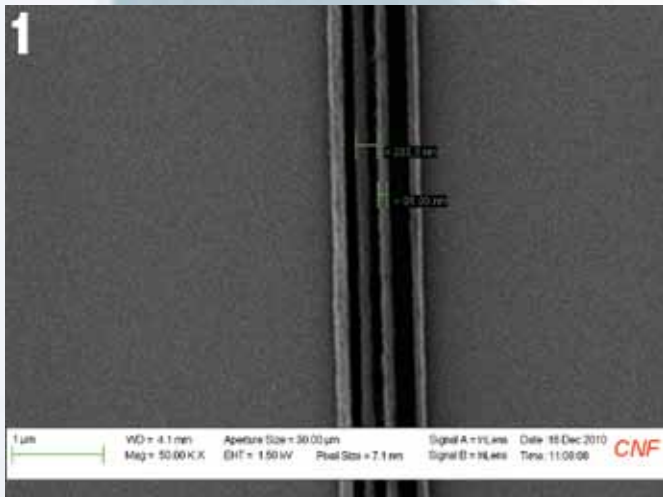
The Gamma is capable of resist coating, baking, and developing wafers of sizes from 3” to 200 mm. There are three precision hotplates available for use with the two spin bowls, one each for coating and developing. A Genmark robot is used to move wafers from one module to the next.

Special features include a Gyrset option for improved uniformity on difficult surfaces, and an AltaSpray X and Y spray dispense module for substrates which cannot be spin-coated.

This tool brings high-uniformity and reliable process control to several CNF lithography areas. The instrument was purchased as part of a collaborative agreement between CNF and SÜSS MicroTec.



Phase Shifting Lithography for the ASML 248 nm Stepper



The system specifications for the ASML PAS 5500/300C DUV stepper include linewidth resolution of 200 nm and an overlay accuracy of 45 nm. This capability successfully bridges the gap between i-line (365 nm) projection lithography and electron beam lithography. Through the recent efforts of CNF staff researchers, John Treichler and Vince Genova, the resolution of linewidths less than 100 nm on a pitch of less than 240 nm has been achieved by the implementation of phase shifting lithography.

With phase shift lithography, the interference of light rays is used to overcome diffraction and improve the resolution and depth of optical images projected onto a wafer. The phase of the exposure light at the wafer is controlled such that adjacent bright areas are formed preferably 180 degrees out of phase with one another. Dark areas are produced between the bright areas by destructive interference, thus improving the linewidth resolution and depth of focus. There are a few ways to fabricate an attenuated phase shifting mask. Phase shifting areas on the photomask may be formed by depositing a phase shifting material of a different refractive index over the chrome (Cr) layer, or by etching relief structures in the quartz substrate. The latter method of etching the quartz to a precise depth of 238 nm, based on an assumed refractive index of the quartz of 1.52 was utilized.

Using a 6-inch mask blank from Telic, the mask pattern was generated with the Heidelberg DWL2000 using the

4 mm head. Linewidths approaching 600 nm in dimension were formed on the mask. The phase shifting pattern is developed and the Cr layer is then etched using conventional wet chemicals or is dry etched in the Trion Mini-lock III ICP using Cl_2/O_2 plasma chemistry. After removal of the photoresist in this initial patterning, the quartz is then etched to the prescribed depth of 238 nm using CF_4 -based chemistry in the PlasmaTherm 72 RIE system. S1805 photoresist is then reapplied to the mask for the patterning of the opaque layer. The opaque layer must be accurately aligned with respect to the phase shifting layer.

Not only is the alignment critical, but the accuracy and uniformity of the quartz etch depth is even more critical. Precise characterization of the etch rate, along with proper chamber conditioning is needed for success. The results illustrated in Figure 1 were achieved with the ASML using UV210 and AR3 BARC, and demonstrate 99 nm linewidths on a 233 nm pitch. The results in Figure 2 show linewidths of 144 nm and spaces of 185 nm using the same phase shifting mask and resist systems.

Further development work is planned on attenuated phase shift masks using novel fluorocarbon based chemistry for quartz etching. We also plan to develop a process for fabricating embedded attenuated phase shifting masks (EAPSMs) using MoSi layers within the quartz. For further information please contact John Treichler or Vince Genova.

Using the ASML DUV Stepper to Produce Grayscale Images in MMA

By John Treichler

Grayscale lithography produces a pattern in the varying thickness of a photoresist. This is particularly useful for making optical devices such as lenses or computed phase plates. To control the thickness of the resist accurately, it helps to have a low contrast resist with, ideally, a linear dose vs. resist solubility response. Most deep ultraviolet (DUV) resists are chemically amplified and high contrast. It was found that MMA, an e-beam resist, could be exposed, with a reasonably flat response, at a dose range from 0-8000 mJ; see Figure 1.

To produce the smoothest profiles with the fewest photo-masks, the exposed images were created to overlap one another so that n images would produce $2n$ discrete

heights in the resist. A complication of this approach is that at the time the layout (CAD) is drawn, the dose response curve and the specific doses for the images must be chosen. The pattern is exposed with an equal dose increment between steps in photo resist height, not equal step heights. Contrasting with e-beam grayscale patterning, the advantage of optical patterning is: 1) speed, minutes vs. days or more, 2) no or much less periodic distortion from field or subfield stitching, and 3) less distortion due to the difficulty of fracturing curves into trapezoids for e-beam exposure. On the other hand, the design of the CAD is more difficult, and if the process changes, new CAD and reticles must be made.

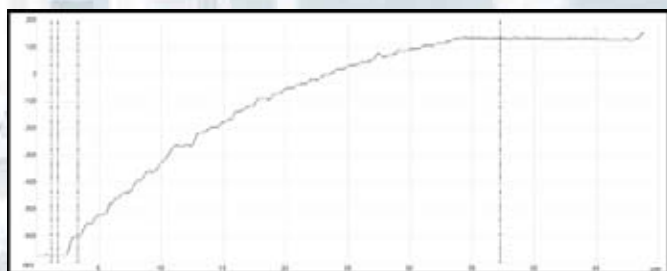


Figure 1: AFM section shows linear dose increment (~250 mJ/ μm) vs. resist height.

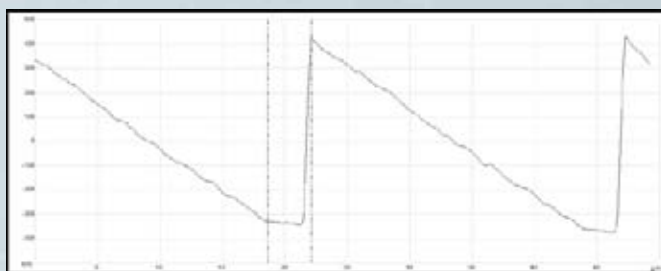


Figure 3: AFM of blazed grating showing.

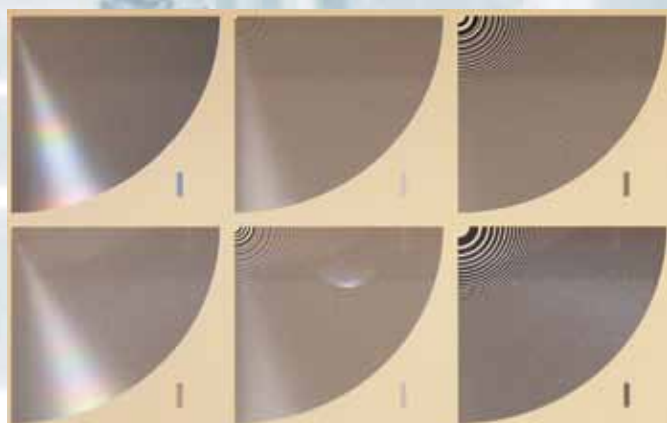


Figure 2: Reticle with six images for exposing lens and blazed grating with 64 steps.

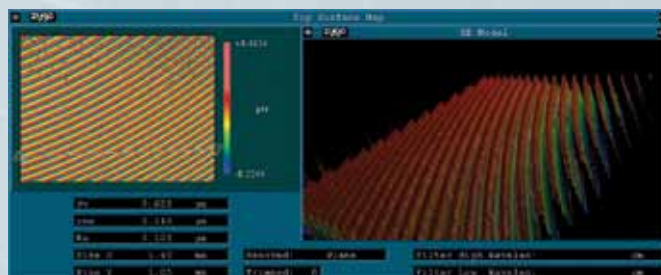


Figure 4: Optical profilometer measurement of lens. Artifacts from measurement.

**Find out about the entire
CNF tool set by going online:
[http://www.cnf.cornell.edu/
cnf5_tool.taf](http://www.cnf.cornell.edu/cnf5_tool.taf)**

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Your comments are welcome!

CNF NanoMeter • Volume 20 • Issue 1

The Cornell NanoScale Science & Technology Facility (CNF) has been serving the science and engineering community since 1977. The CNF is supported by the National Science Foundation, the New York State Office of Science, Technology & Academic Research, Cornell University, Industry, and our Users.

The NanoMeter is published by the Cornell NanoScale Science & Technology Facility, and is printed on 10% post-consumer paper, using soy-based inks. We encourage you to reduce, reuse and recycle!
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