NanoMeter

The newsletter of the Cornell NanoScale Science & Technology Facility

Spring 2007 • 30th Anniversary Issue • Volume 17, Number 1

Directors' Column

It is with great pleasure that we present to you the 30th Anniversary Issue of the NanoMeter. It has been a very exciting 30 years, throughout which CNF has continuously evolved and remained at the forefront of nanoscale science and technology. CNF started as the National Research and Resource Facility for Submicron Structures (1977-1987), then became the National Nanofabrication Facility (1987-1993). For these 16 years it was the nation's sole nanofabrication user facility. With the establishment of the National Nanofabrication Users Network, it was renamed the Cornell Nanofabrication Facility (1993-2002), and became part of a five-site network. The former evolved to the National Nanofabrication Infrastructure Network and expanded to 13 sites, and CNF became the Cornell Nanoscale Science & Technology Facility you are familiar with today. The one constant throughout these years has been the outstanding quality and dedication of the CNF staff. Let this 30th anniversary celebration stand as a testament to the quality of our staff, who rightly deserve the credit for all the good things CNF stands for, and to whom we are grateful.

As the newest additions to the CNF leadership team, we have quickly come to realize what a special place this is. We gratefully acknowledge the strong leadership and vision of the directors who came before us and hope to make our own positive mark on this venerable institution. As you read this special issue of the NanoMeter, you'll encounter snapshots from the past, present and future of the CNF, including testimonials from past directors and samples of the cutting edge research taking place here. Sandip Tiwari's special tribute to the people of CNF inside this issue, is especially appropriate in this regard, particularly with respect to future plans for the CNF. We also know that without the generous support and guidance given by the Cornell Faculty and Administration, the CNF would not be the vibrant enterprise that has successfully redefined itself so many times over its 30 year history.

For the friends of CNF who are traveling to our "Future of Nanotechnology" Symposium in celebration of the 30th Anniversary, we hope that you will not only enjoy the outstanding technical program assembled, but will also have the opportunity to become reacquainted with former colleagues, as well as taking the time to learn about the new and exciting changes happening inside Duffield Hall. Our thanks to the Kavli Institute, our staff, and all the participants for helping to make our 30th a celebration to remember.

Warm regards,

George Malliaras, Lester B. Knight Director

Donald Tennant, Director of Operations

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Fatty acids, nanotubes and hospital inventories: a spectrum of undergraduate majors presented at spring research forum

Abridged Article by Anne Ju
Cornell Chronicle

Theories behind people's eating habits and ideas on revamping hospital inventory management were just two of the nearly 100 Cornell undergraduate research topics featured at an April 18 research showcase in Duffield Hall.

The 22nd annual Spring Undergraduate Research Forum, hosted by the Cornell Undergraduate Research Board (CURB), included work of undergraduate students from a wide range of majors. Meant to promote undergraduate-level research, the event included a keynote speaker, oral presentations and posters that lined the Duffield atrium.

For some rookie researchers, the forum was a first crack at explaining their lab work to curious passers-by. For others, such as electrical and computer engineering (ECE) student Eric K. Yu '08, it was a venue to demonstrate experience and enthusiasm for a particular subject.

As friends or strangers approached Yu's poster on carbon nanotubes, the lanky junior patiently explained the difference between graphene and graphite as different forms of the element carbon, and why carbon nanotubes hold promise for a new generation of transistors. Yu works under the supervision of ECE professor Sandip Tiwari and research associate Derek Stewart.

Winners of the 22nd Annual Spring Research Forum

Hello undergraduate researchers and friends, I would like to once again thank you all on behalf of the CURB executive board for your participation in the Spring Research Forum, it was a great success, and by all means because of you. The final results for the winners of the best presentations are as follows:

1st place: Eric Yu '08,
Electrical and Computer Engineering (abstract 96)

2nd place: Rohit Gupta '07,
Electrical and Computer Engineering (abstract 35)

3rd place: Amanda Koltz, '07
Biological Sciences (abstract 45)

Cheers, CURB Executive Board '07

Hello, Derek and Prof. Tiwari:
Many thanks to Prof. Tiwari -- he handed me the research forum postcard he got in his mailbox and told me "Eric, you must sign up for this." This should look on my CV when I apply to grad school. Also, you can never complain about a free $400 cash.
Cheers, Eric

Folks:
Derek Stewart, has been co-supervising an undergraduate student, Eric Yu, in doing some important calculations regarding properties of graphene and carbon nanotube. I am writing this note to express my thanks and recognition of Derek and the CNF cluster which made this possible. Computing makes very good undergraduate projects that are very pertinent to the science we do.

Regards,
Sandip Tiwari
ECE & NNIN

Using synthetic DNA, Cornell researchers fashion low-cost, biodegradable hydrogels for drug delivery and tissue engineering

By Bill Steele
Cornell News

Using synthetic DNA formed into crosses, Y's and T's, Cornell researchers have created biocompatible, biodegradable, inexpensive hydrogels that can be easily formed into any desired shape for biomedical applications.

Hydrogels are liquid or semisolid materials composed of long-chain molecules cross-linked to one another to create many small empty spaces that can absorb water or other liquids like a sponge. If the spaces are filled with a drug, the hydrogel can dispense the drug gradually as the structure biodegrades. Widespread research also is under way on using hydrogels as scaffolds for tissue engineering and tissue repair, where the spaces in the gel might be filled with stem cells, tissue-growth factors or a combination of both.

A hydrogel shaped to spell CORNELL

Molecular Bioengineering Lab/Cornell University

To demonstrate that DNA hydrogels will hold their shape for such applications as tissue engineering, Cornell researchers molded samples to spell out "CORNELL." The sample at the top, about three centimeters long, is stained with a dye that fluoresces red under ultraviolet light (center). The sample at the bottom, about 3,500 microns (millionths of a meter) long, was created in a mold etched into a silicon chip at the Cornell NanoScale Facility and stained with a green fluorescent dye.

Hydrogels for these purposes are usually made from organic or inorganic polymers (molecules that form long chains), such as alginate from seaweed. Some have been made from proteins but none entirely from ordinary DNA. So far, all these processes have used organic solvents or acids or involve high temperatures, making conditions too harsh for a drug or living cells, so the materials to be encapsulated must be loaded in afterward.

The new process, developed in the laboratory of Dan Luo, Cornell assistant professor of biological and environmental engineering, uses no high temperatures or harsh chemicals, so the material to be encapsulated in the gel can be introduced before the gel is formed. Because the gel is made of only synthetic DNA, no immune response should be triggered, the researchers said, so the material encapsulated can include proteins and even live mammalian cells.

The research was published Sept. 24 in the online version of Nature Materials and will appear in a forthcoming print issue of the journal.

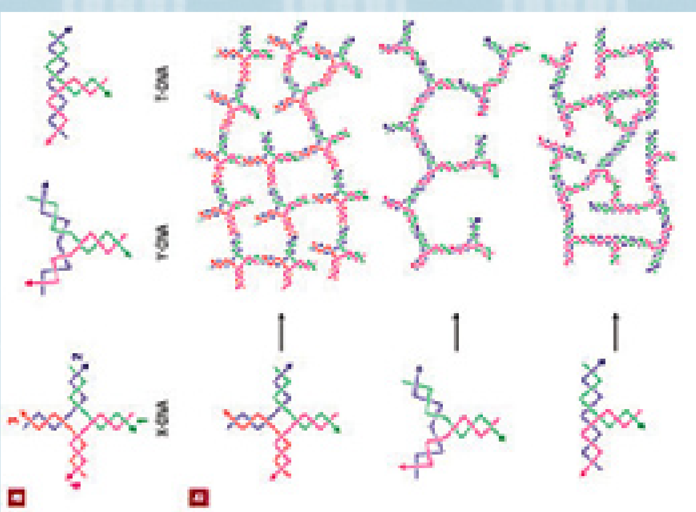
A DNA molecule is a long chain in a sequence that is unique to each chain. Conveniently, two chains with complementary sequences can lock onto one another like two halves of a zipper. By making synthetic DNA chains whose sequences are complementary over only part of their length, Luo and colleagues have created tree-shaped structures.

To create hydrogels, they made branched DNA that formed itself into crosses, Y's and T's with "sticky" ends that could link to each other with the help of enzymes known as ligases.

The researchers found that they could easily alter certain properties of the resulting gelatinous materials, including rigidity and absorbency, by adjusting the types of branched DNA used and the concentration of DNA in the mix. To demonstrate the ability of some of the materials to hold their shape, the researchers created them in a variety of different molds, including some that spelled out "CORNELL" at centimeter and nanoscales.

To test the use of the DNA hydrogels for delivering drugs, the researchers encapsulated porcine insulin and the anticancer drug Camptothecin and observed that the drugs were released in a controlled manner over time. When they encapsulated live cells in a gel, they found that the cells were still alive three days later.

Co-authors with Luo are Cornell graduate students Soong Ho Um, Jong Bum Lee and Sang Yeon Kwon, postdoctoral researcher Nokyoung Park, and Christopher Umbach, Cornell assistant professor of materials science and engineering. The research was partially supported by the Cornell Center for Materials Research, Cornell Center for Advanced Technology and a National Science Foundation Early Career Development Award, and some was performed at the CNF.



Molecular Bioengineering Lab/Cornell University

DNA chains that attach to one another along part of their length can self-assemble into branching structures including crosses, T's and Y's. In the presence of enzymes that connect the open ends to one another, these shapes combine into larger structures with many small openings, creating a sponge-like material called a hydrogel.

Reach out and touch an oscillator: Cornell researchers find a new way to read nanoscale vibrations

By Bill Steele
Cornell News

Nanomechanical oscillators - tiny strips of vibrating silicon only a few hundred atoms thick - are the subject of extensive study by nanotechnology researchers. They could someday replace bulky quartz crystals in electronic circuits or be used to detect and identify bacteria and viruses.

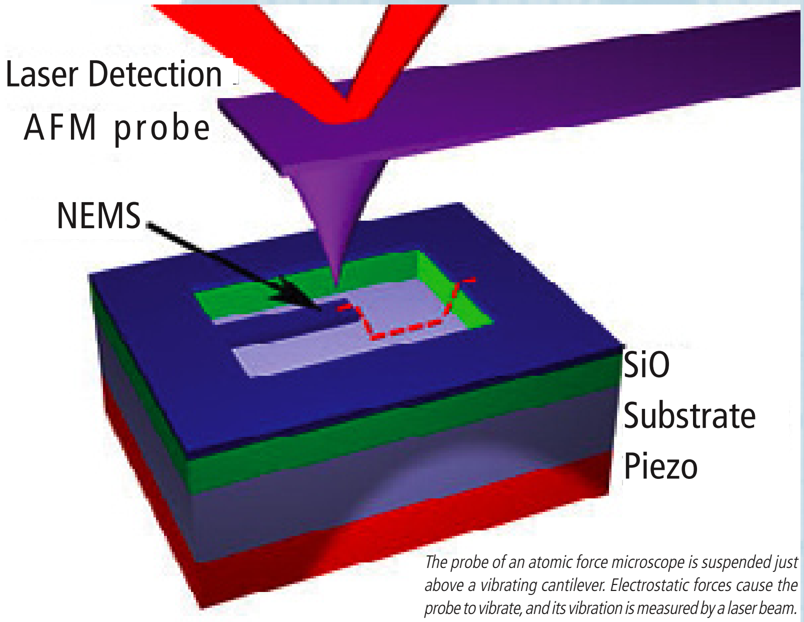
The catch is that measuring their vibrations isn't easy. It is usually done by bouncing laser beams off them - which won't work when the nanodevices become smaller than the wavelength of the light - or with piezoelectric devices - those bulky quartz crystals we're trying to get rid of.

Now Cornell University researchers have come up with a very simple solution: reach out and touch them. The vibration of the tiny oscillators can be measured by "tapping" with an atomic force microscope (AFM).

"AFMs are all over the place," said Rob Ilic, research associate in the Cornell NanoScale Facility and lead author on a paper about the research published Feb. 23 in the online edition of the Journal of Applied Physics. "So this offers a simple way to study these structures." (Cornell, for example, has at least a dozen AFMs in various labs.) Moreover, he said, probes similar to those in an AFM can be built directly into nanofabricated devices.

This would amount to using MEMS to measure NEMS, he said. MEMS (microelectromechanical systems) are machines with moving parts measured in microns, or millionths of a meter; NEMS (nanoelectromechanical systems) are measured in nanometers, or billionths of a meter. When the NEMS oscillator is too small to be observed by laser light, it could still be coupled to a MEMS probe that in turn would be large enough for a laser readout.

To measure the vibration of a nanomechanical oscillator, the AFM probe moves along the length of the oscillating rod. The result is a complex bouncing interaction between the probe and the oscillator -- imagine shaking one end of a spring and watching the vibrations at the other end -- from which the frequency of vibration of the oscillator can be determined mathematically.



The probe of an atomic force microscope is suspended just above a vibrating cantilever. Electrostatic forces cause the probe to vibrate, and its vibration is measured by a laser beam.

For the experiments just reported, Ilic and colleagues manufactured a wide variety of silicon cantilevers from 5 to 12 microns long, 1/2 to 1 micron wide and about 250 nanometers thick, which had natural vibration frequencies from 1 to 15 Mhz. The cantilevers were set into vibration by a piezoelectric device.

The experimenters first measured the resonant frequencies of the cantilevers by focusing laser beams on them and observing deflection of the reflected light, then scanned each cantilever with the AFM probe, both in tapping mode and with the probe just above the surface. They found the AFM measurements in good agreement with laser measurements, although the AFM readouts had a somewhat lower "quality factor," because the oscillator and probe were interacting. This would make the method somewhat less precise in mass detection.

Nanomechanical oscillators are often cited as potential tools for detecting bacteria, viruses or other organic molecules. An array of tiny cantilevers might be created with antibodies to many different pathogens attached to them. An experimental solution could then be washed over the array, allowing microbes to bind to the cantilevers with matching antibodies. Since the cantilevers are so tiny, an attached bacterium or virus represents a significant change in mass, which changes the frequency at which the oscillator will vibrate.

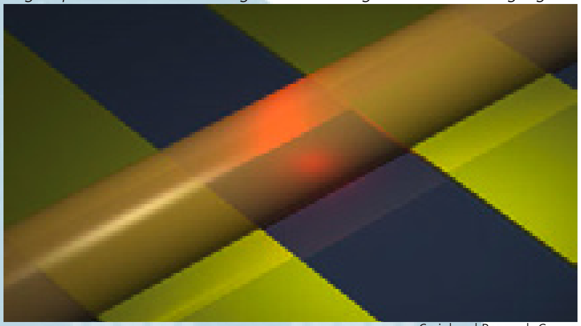
In a practical device, a MEMS probe could be mounted above each NEMS oscillator to read out which oscillators in the array show a change in frequency -- and thus identify which pathogens are present.

Cornell researchers develop virus-size 'nanolamps' that could aid use of flexible electronic devices as sensors

By Anne Ju
Cornell Chronicle

To help light up the nanoworld, a Cornell interdisciplinary team of researchers has produced microscopic "nanolamps" -- light-emitting nanofibers about the size of a virus or the tiniest of bacteria.

An illustrated closeup of an electrospun fiber. During experimentation the organic devices gave off an orange glow.



Craighead Research Group

In a collaboration of experts in organic materials and nanofabrication, researchers have created one of the smallest organic light-emitting devices to date, made up of synthetic fibers just 200 nanometers wide. The potential applications are in flexible electronic products, which are being made increasingly smaller.

The fibers, made of a compound based on the metallic element ruthenium, are so small that they are less than the wavelength of the light they emit. Such a localized light source could prove beneficial in applications ranging from sensing to microscopy to flat-panel displays.

The work, published in the February issue of Nano Letters, was a collaboration of nine Cornell researchers, including first author José M. Moran-Mirabal, an applied physics Ph.D. student; Héctor Abruña, the E.M. Chamot Professor of Chemistry and Chemical Biology; George Malliaras, associate professor of materials science and engineering and director of the Cornell NanoScale Facility; and Harold Craighead, the C.W. Lake Jr. Professor of Engineering and director of the National Science Foundation-funded Nanobiotechnology Center.

Using a technique called electrospinning, the researchers spun the fibers from a mixture of the metal complex ruthenium tris-bipyridine and the polymer polyethylene oxide. They found that the fibers give off orange light when excited by low voltage through micro-patterned electrodes.

"Imagine you have a light bulb that is extremely small," said Malliaras, an organic materials expert. "Then you can use the bulb to illuminate objects that you wouldn't be able to see otherwise."

Craighead's research group, which focuses on nanostructures and devices, supplied the expertise on the electrospinning technique.

The technique, explained Moran-Mirabal, who works in Craighead's laboratory, can be compared with pouring syrup on a pancake on a rotating table. As the syrup is poured, it forms a spiraling pattern on the flat pancake, which in electrospinning is the substrate with micropatterned gold electrodes. The syrup would be the solution containing the metal complex-polymer mixture in solvent. A high voltage between a microfabricated tip and the substrate ejects the solution from the tip, Moran-Mirabal said, and forms a jet that is stretched and thinned. As the solvent evaporates, the fiber hardens, laying down a solid fiber on the substrate.

As scientists look for ways to innovate -- and shrink -- electronics, there is much interest in organic light-emitting devices because they hold promise for making panels that can emit light but are also flexible, said Moran-Mirabal.

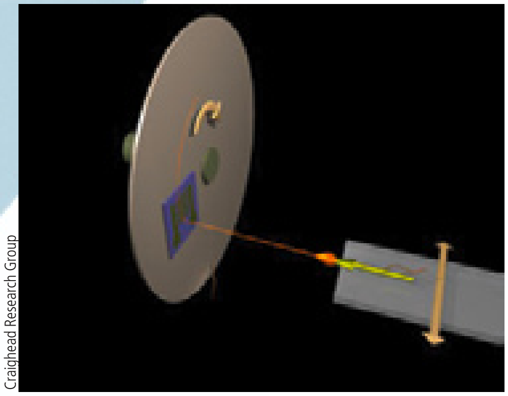
"One application of organic light-emitting devices could be integration into flexible electronics," he said.

The research also shows that these tiny light-emission devices can be made with simple fabrication methods. Compared with traditional methods of high-resolution lithography, in which devices are etched onto pieces of silicon, electrospinning requires almost no fabrication and is simpler to do.

The durability of organic electronics is still under investigation, and this recently completed research is no exception, Craighead said.

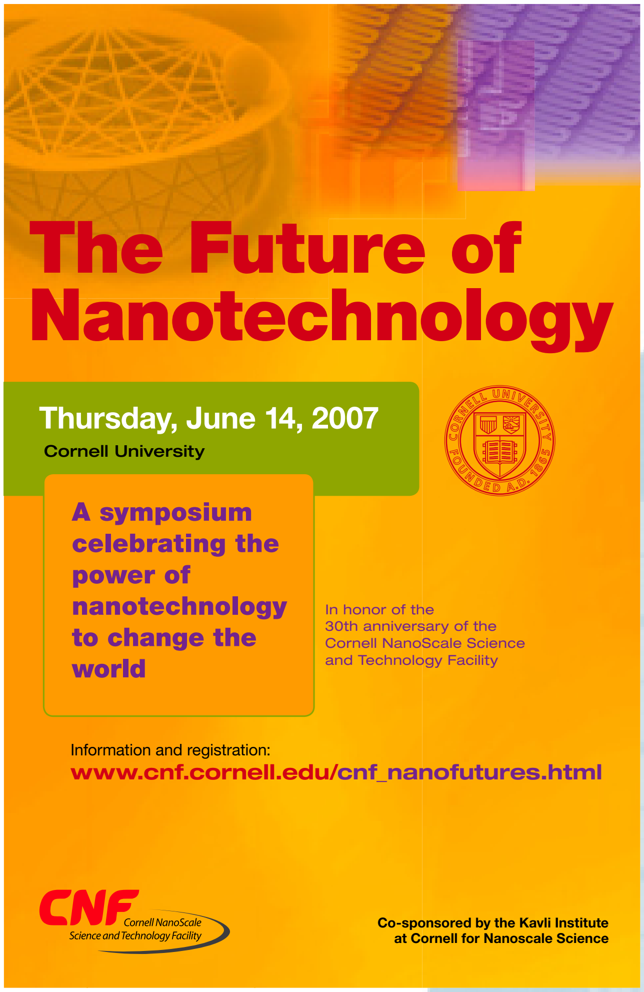
"The current interest is in the ease with which this material can be made into very small light-emitting fibers," he said. "Its ultimate utility, I think, will depend on how well it stands up to subsequent processing and use."

Other co-authors on the work are graduate students Jason D. Slinker, John A. DeFranco, Scott S. Verbridge, Samuel Flores-Torres and CNF staff member Rob Ilic.



Craighead Research Group

Cornell researchers used the process of electrospinning, illustrated here, to create one of the smallest light-emitting devices to date. A voltage between a microfabricated tip and a substrate ejected a ruthenium-based solution from the tip, creating the thin fibers.


The Future of Nanotechnology
Thursday, June 14, 2007
Cornell University
A symposium celebrating the power of nanotechnology to change the world
In honor of the 30th anniversary of the Cornell NanoScale Science and Technology Facility
Information and registration:
www.cnf.cornell.edu/cnf_nanofutures.html
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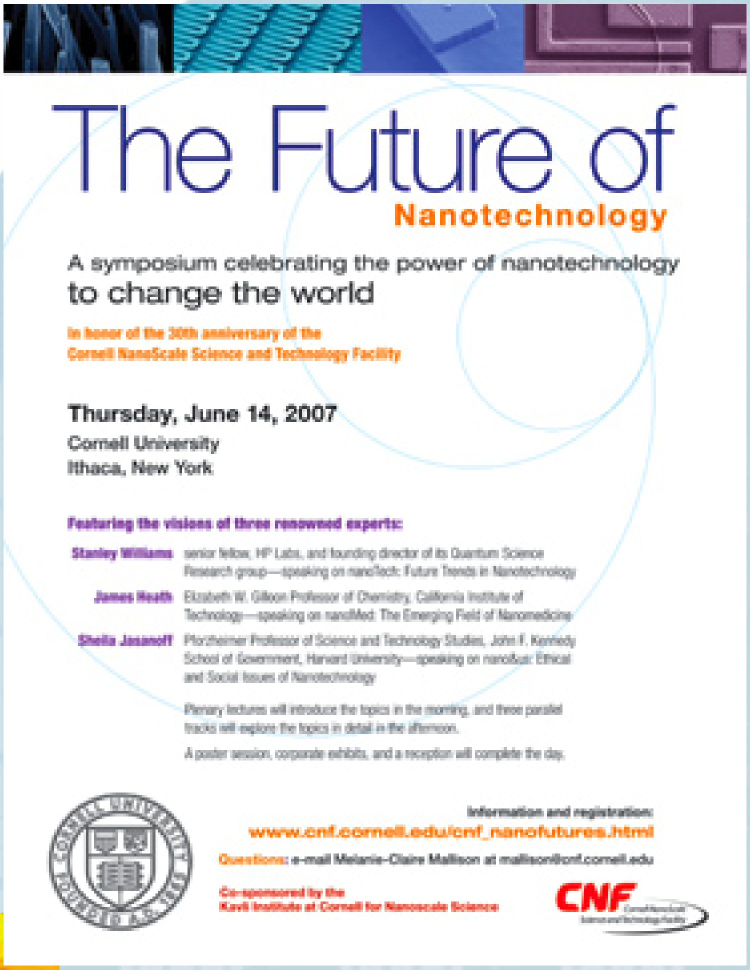
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James Heath Elizabeth W. Gilloon Professor of Chemistry, California Institute of Technology—speaking on nanoMed: The Emerging Field of Nanomedicine
Sheila Jasanoff Pforzheimer Professor of Science and Technology Studies, John F. Kennedy School of Government, Harvard University—speaking on nano&us: Ethical and Social Issues of Nanotechnology
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Questions: e-mail Melanie-Claire Mallison at mallison@cnf.cornell.edu
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Kavli Institute at Cornell
Journalist's Workshop in Nanotechnology
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The Kavli Institute at Cornell workshop features:
a primer on nanoscale science: How do scientists work with stuff so small?
hands-on experiences in nanolabs: Suit up for the clean room and make your own nano device.
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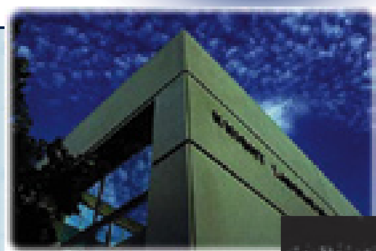
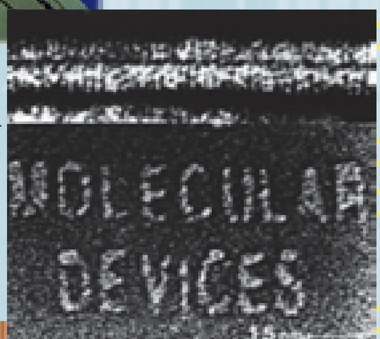
2007 CNF Staff

First Row: Sam Wright, Kathy Springer, Denise Budinger, George Malliaras, Don Tennant, Jim Clair, Garry Bordonaro
Second Row: Carol Cleveland, Meredith Metzler, Mike Skvarla, Edward Camacho, Karlis Musa, Dave Botsch
Third Row: Alan Bleier, Vince Genova, Derek Stewart, Mandy Esch, Ana Viseu, Kelly Baker, John Treichler, Jerry Drumheller
Fourth Row: Daron Westly, Lynn Rathbun, Dan Woodie, Melanie-Claire Mallison, Paul Pelletier, Phil Infante, Gabriel Terrizzi
Inset: Rob Ilic

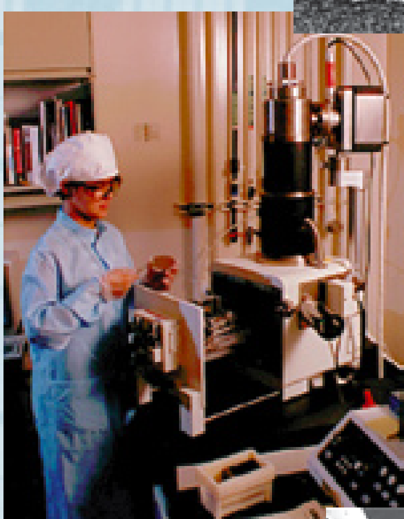
Memories of the Cornell Nano Scale Science & Technology Facility 1977-2007



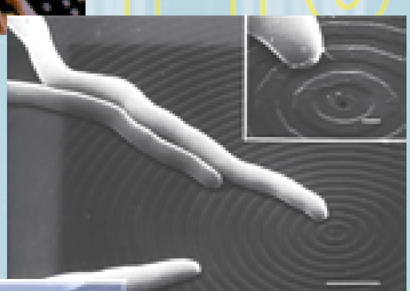
Knight Lab 1982



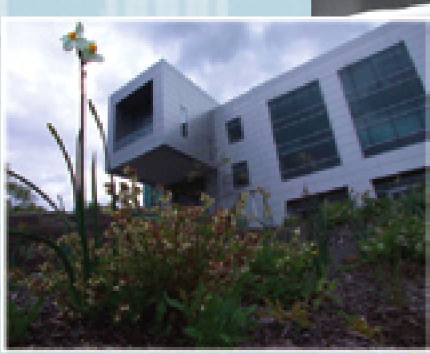
Professor Michael Isaacson of Cornell creates the smallest man-made pattern ever reported, 1981



CNF REU Intern, Ana Ortiz, 1995



Transmission of the Signal for Cell Differentiation in the Fungus, Uromyces H.C. Hoch and R.C. Staples, CNF Project #267-86, circa 1999



Duffield Hall 2007

The Birth of the NRRFSS

To the best of my recollection, here is NRRFSS Day 1.

I was finishing my M.Eng. in May of 1977. One day while I was walking down the 4th floor hallway in Phillips Hall, Andrea Schwoeble, the ECE secretary, said "Joe Ballantyne is looking for you!"

I didn't think I was in trouble, but the thought did cross my mind.

I found Joe and he said, "There is an NSF presentation TOMORROW! Take your M.Eng. results to Ray Coles in Bard Hall, and tell him Joe sent you." Being included in the presentation was a great honor for me, and this was my first opportunity to take an SEM image.

When I returned from Bard Hall, Joe said, "After you make your vu-graph, would you like to HAND CARRY the presentation to NSF in Washington DC?" I would have been thrilled to go, but I had a prior commitment, so I suggested that Steve Kratzer was a good choice since he had family in DC.

The presentation must have gone well, because the next day, Cornell University won the first five year grant for the National Research and Resource Facility for Submicron Structures (NRRFSS).

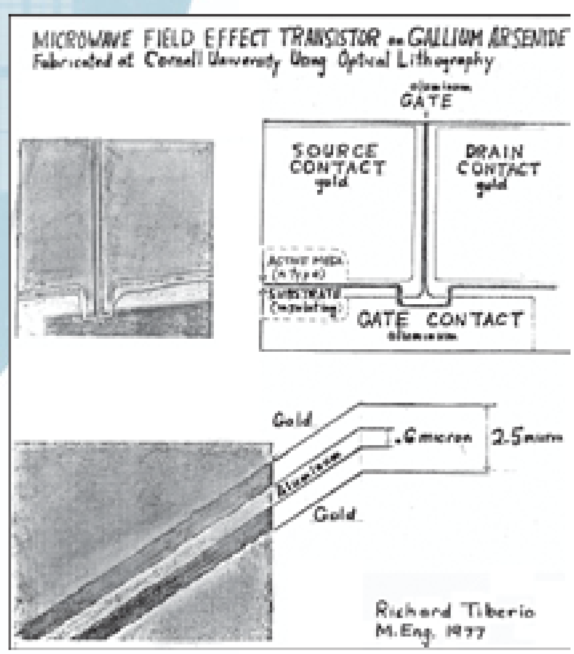
This was all fortuitous as it provided me a career opportunity: two years later, in 1979, I returned to the NRRFSS at Cornell to install and operate the first Cambridge EBMF e-beam system. See photo.

Good luck with the next 30 years!

Richard Tiberio

BS '76, M.Eng '77, PhD '94

CNF Staff, 1979-2000



Here is a copy of that vu-graph that went to NSF. (Don't laugh, they were all hand-drawn back then.)

Seven NRRFSS/NNF Memories

1. In the beginning (for me):

It must have been during the first month after my arrival at Cornell, in the summer of 1978, as I was pushing a heavy vacuum roughing pump, which was strategically positioned on pieces of cardboard to reduce friction, down the 3rd floor hallway of Phillips, that I fully understood why the overhead rate at Cornell was less than half of what it was at the Hughes Research Labs from where I had just come. The full-time NRRFSS staff at that time consisted of Andrea Schwoeble (administrative assistant), Nelson Allen (machinist) and myself. Fortunately we were able to enlarge the staff over the next several years, and in the process probably caused a rise in the Cornell overhead rate.

2. Provost Keith Kennedy approves ground-level site for the facility:

This was a big deal for the facility and literally put us on a firm footing! Provost Kennedy had just been involved with a less than satisfactory placement of a scanning electron microscope in the Vet School. So when I described the stability that was needed for microfabrication, he understood the need. Later I would have to go before the Cornell Board of Trustees meeting in NYC to help justify the additional funds needed to complete the Knight Lab. Earlier President Dale Corson had approved $600k for the construction of the facility in the NRRFSS proposal (which may have won the proposal for Cornell); however, the final price tag of $4.3M for the Knight Lab was a little over budget.

3. Prof. John Silcox and I thwarted unwanted ac magnetic fields in Knight Lab:

While the STEM was in its interim location on the third floor of Phillips Hall, it was discovered that there were unacceptable ac magnetic fields apparently emanating from the old reinforcing iron used during the construction of Phillips Hall. These fields were assumed to be caused by circulating ac currents in the re-enforcing iron bars. Therefore, during the construction of Knight Lab, we placed Tygon tubing at each tie point of the rebar to electrical isolate each rod. On-sight isolation was confirmed prior to pouring the meter-thick concrete floors. We observed no ac magnetic fields in the floors of Knight Lab, so we assumed our efforts were successful.

4. Deans were absolutely critical in the success of NRRFSS:

I remember vividly have a glass of wine with Dean Edmund Cranch and Prof. Jack Oliver in Carpenter Hall as I was interviewing for the directorship of NRRFSS and for a professorship in the School of Electrical Engineering. I was quite impressed until I realized they had just received word of a large donation that would make the new geology building possible, and it was to this that we were celebrating. Dean Tom Everhart had many important inputs to the success of NRRFSS, I will mention only two; one the funding of the Knight Lab, and two on a tactical level, he advised we could disassemble the large air handler for Knight Lab and install it later rather than delay critical construction because of its late delivery on site.

5. The smell of onions in the ebeam lithography lab:

Over Christmas break in December 1983, John Sanford, Nelson Allen and I donned our clean room attire and initiated the gene-gun shot that reverberated not only within the Knight lab, but also throughout the genetic transformation community. A few days before, I had purchased a Crossman air pistol at Fay's Drugstore for $39.95, which Nelson had drilled and tapped two small holes in the barrel for the insertion of µm-size tungsten powder. That evening, and in subsequent evenings, we were able to demonstrate multi-cellular depth penetration and the lodging of multiple particles within a single cell of onion as we fired µm-size tungsten powder into layer after layer of peeled onionskin. After two-years of hard dedicated research and much refinement by John and his post-doc Ted Klein, they had demonstrated that the gene gun technology was for real, but not without much laughter from the sidelines and rejection of our papers because of the crudeness of the method. Nevertheless, John and I co-founded Biolistics, Inc., in the fall of 1986, and we both left for sabbatical leaves – John to Duke University and me to Cambridge University. Later on the gene gun found its place among the preferred methods for genetic modification – two of our early gene guns are on permanent display at the Smithsonian Institution in Washington, DC and one is (was) in use at Epcot Center in Orlando, FL.

6. Back to the 1986 Staff at the Facility:

Time flies and I was off to Cambridge University for my sabbatical leave in 1986-87 with Professor Alec Broers (now Lord Broers) in the Engineering Department, home of the development of the SEM in the late 1950s and early 1960s under Sir Charles Oatley. We had just submitted our NSF proposal in the summer before I departed for the next 5-year renewal of what was to become the National Nanofabrication Facility. Prof. Noel MacDonald was the acting director in my absence and as usual, the facility carried on marvelously under the self-attention of the staff, with little to no attention

Seven NRRFSS/NNF Memories

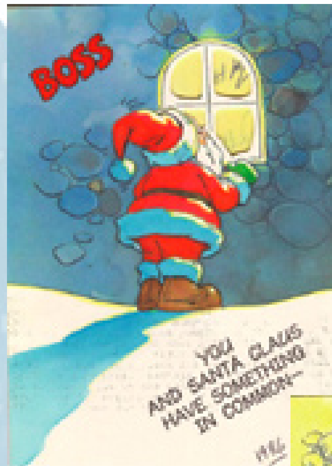
from me, but somewhat more attention from Dr. Greg Galvin, associate director, and Prof. MacDonald. The staff also had the time to send me a Christmas card and an accompanying photograph of the NRRFSS staff as of 1986, as shown below: Because of their thoughtfulness, we have a snapshot in time, after 21 ensuing years, of this young staff that played a predominant role in shaping what was to become NNF, NNUN and NNIN. We owe them and all CNF staff, past and present, a debt of gratitude. Their dedication and expertise is forever imprinted on what is CNF.

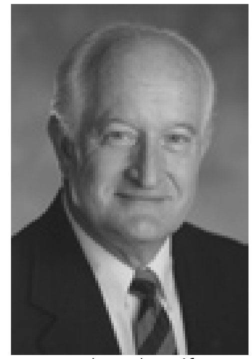
7. Lucky to have only one broken leg after 10 years as director:

At a January 1989 NNF Policy Board Meeting at Sandia Laboratories at the end of my directorship, I was presented with a Hopi Kachina doll, a Wolf Doctor. Unfortunately, it had a broken leg. I can't remember if I said or another member of the board said, "--- lucky to have only one broken leg after being director of NNF for 10 years". On a more serious note, it was an honor and a privilege to be the first director of NRRFSS. It was challenging, as all of us who were involved early on know; however, the journey was well worth the effort. I came to appreciate greatly several key faculty members who were always there, and still remain, at the ready, in support of the facility. Successive Cornell administrations were behind the effort in the beginning and saw it through these 30 years with great effort, with close supportive attention, and, I believe, with great enthusiasm. Cornell University and nanoscale science and technology have become synonymous and the country is the better for it.

Edward Wolf

CNF Director 1978-1988





Edward Wolf

Chrstmas Card from NRRFSS Staff members to Ed Wolf, 1986

Fall 1986 NRRFSS Staff (left to right): Gyorgy Porkolab (Wolf grad student), Greg Galvin, Greg Kisaky, Debbie Sladich, Rich Tiberio, Ruby Clark, Dennis Costello, Joanie Rowe, Tim Whetten, Nellie Whetten, Lynn Rathbun, Brenda Bryant, Mike Skvarla, Brian Whitehead, Steve Burgess, Dan Dinsmore, Jerry Comeau, Bob Soave, and Rick Bojko.

The NNF Years

I found the position of Director of the National Nanofabrication Facility to be a unique vantage point from which to observe the many scientific disciplines and applications that could take advantage of nanoscale materials processing. In some areas, such as electronic device research, the use of nanofabrication approaches was well established and novel nanostructures could be studied for physical phenomena that could potentially be exploited in improved device designs or enhanced device performance. However, in areas such as biology and medical research, nanofabrication methods were not widely utilized. To me, it appeared that these were rich areas in which nanofabrication methods could have major impact. The NNF had the expert staff, ablility to deal with diverse users, and as Director I was in a position to encourage research in the biological areas and expand the NNF user community in the biological and medical disciplines. We have witnessed great increase in activity in this area since that time.

Cornell has been a leader in the development of new nanofabrication approaches and the utilization of these methods in interdisciplinary research, and I have been pleased to participate in this effort. It is clear to me that the possibilities for using the tailored properties of nanoscale structures were well established at Cornell well before the explosive interest stimulated by the National Nanotechnology Initiative. I look back on my time as Director as a stimulating and exciting period of my life.

Harold G. Craighead

NNF Director, 1989-1993

Lester B. Knight Director, 1993-1995

The CNF Staff

Great hard working staff—that's my memory! Speaking of staff, I remember the random access filing system designed by the lab manager. His filing system for lab manuals, scientific papers and lab reports was 15 to 20 piles of paper randomly dispersed around his office - not one square inch of desk space was visible. When I would ask him for a service manual or report, I would go with him to his office to see if he could find the manual; he usually found the desired document within a day of the request.

Another thing I remember when I was Director is that my heart would skip a "few beats" every time I heard sirens on campus. I always checked to see if the fire trucks were on their way to the Submicron Facility.

Again, I remember working with a great staff; they provided excellent service to our customers.

Noel C. MacDonald

Lester B. Knight Director, 1995-1997

The NNUN Years

I was privileged to serve as CNF Associate Director from May, 1994, through December, 2000, a large fraction of the span of existence of The National Nanofabrication Users Network (NNUN). During that period of time, four CNF Directors – Harold Craighead, Noel MacDonald, Joe Ballantyne, and Sandip Tiwari – served with distinction and then moved on. So Lynn Rathbun and I were the threads of continuity throughout NNUN's existence.

Actually, much of the difficult work was done, just before I arrived, by Harold and others in defining NNUN and securing the funding. Being new to CNF, I also profited greatly from the guidance of former CNF Director Ed Wolf. As we commenced NNUN operations, I would occasionally hear some mild skepticism (cynicism?) about the feasibility of getting five disparate schools – Cornell, Howard, Penn State, Stanford, and UCSB – to stay on the same page. But the bottom line is that we indeed did cooperate beautifully, and being associated with NNUN was one many pleasant aspects of my tenure at CNF.

This was a period of very rapid growth for CNF, and Knight Lab was bursting at the seams. Staff were jammed into tiny offices with predictable effects. We couldn't sort office assignments by political preference, and in one case a poor staffer had to listen to a noontime ultra-conservative talk show from her office mate's radio. Conversely Denise Budinger I'm sure became tired of listening to the classical music emanating from my office! The small offices meant that Lynn Rathbun's space was perpetually a disaster area. I recall on one or two occasions that Carol Cleveland simply took things into her own hands, marched in, and cleaned up the rubble. I think the time constant for return to equilibrium was about 2 days.

The network was very fortunate to have two champions at NSF, Larry Goldberg and Rajinder Khosla, who provided support and ran interference (I'm sure on many occasions unbeknown to us). In addition to the expected sharing of students and resources within NNUN, we initiated two programs with enthusiastic support from NSF

The first program was to enhance our support to biology users. With supplemental funds from NSF, we were able to hire Greg Baxter at CNF and Mary Tang at Stanford. They worked together, e.g. developing workshops, and in general encouraging the biology community to use NNUN. Greg subsequently left CNF to participate in a start-up (a spin off of his collaboration with Prof. Mike Shuler at Cornell). His role is now ably filled by Mandy Esch.

The second program was our network-wide Research Experience for Undergraduates (REU) program. I recall tossing the idea out at an NSF review meeting. They were immediately very supportive. A few days later, Lynn came up with the great idea that we should incorporate a network-wide convocation. This really tied things together and added an exciting dimension to the program. The myriad details of making such a complicated program work fell to Melanie-Claire Mallison, who performed that role beautifully. I still stand in awe as to how she coordinated a disparate collection of faculty, staff, and students at five schools to make a coherent program. If that weren't enough, her second act is to repeat the process for NNIN with its 12 schools. It's that kind of dedication and competence which made my NNUN years so easy and enjoyable.

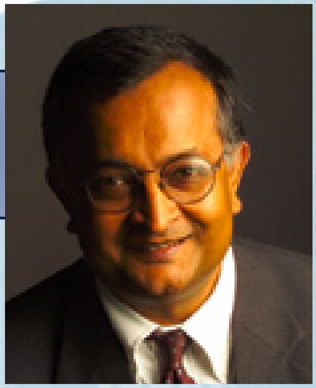
Alton Clark

CNF Associate Director, 1994-2004

Photo provided by Dr. Clark

Alton and Donna Clark in front of the harpsicorde he built and they donated to Ithaca College.

People First



People are the heart of an effective organization. For CNF, it is the staff and its user community helping and expanding the frontiers of research. The period of 2002 to 2003 was singular in changes at CNF. Building of Duffield Hall, moving from the old laboratory to a new building that stands above and around it, continuity in research work, finding workable compromises between vested individual and broader community interests for the new building, organizing and competing for the ten year national network, and acquisition of major new instrumentations with limited budgets, all happened simultaneously and left many of us with little time for sleep. Such periods, in hindsight, are either enervating – a time that we try to forget, or nourishing – an experience that we derive strength and learning from. Such periods also leave behind many memorable moments. I write this short commentary in gratitude to the CNF people and its community recalling some of the delightful irrationality of that period.

Getting a number of advanced instruments directly into the new space was a major task for us and we had accumulated and planned for some of this. Money, however, is always short and funding sources for capital equipment limited. We succeeded through a well-crafted proposal for an electron beam lithography system in an NSF competition that rarely awards million plus dollars. The collateral consequence of this was the need for more funds and minimizing of all costs while assuring working high quality tools that would be new source of strength for the laboratory. Luck was with us in the form of the optics and dot com bust that followed the "effervescence" of late 90's. Lynn Rathbun was regularly participating in equipment auctions on the phone. Many of the CNF staff, particularly Phil Infante, Rob Ilic and Daron Westly kept traveling at short notice to check equipment we were interested in; Rob and Daron and Garry Bordonaro and John Treichler spent considerable time at Bell Laboratories and with Leica Instruments in evaluating electron-beam lithography machines using tests developed with the guidance of experts, including Edward Wolf, our first director. Meredith Metzler became a night owl. During the unfolding of all these events, CNF as a working place was still going on with its central function of research, guided in good spirit by Michael Skvarla, and finessed by Kathy Springer, who had just arrived, and Carol Cleveland. All this, while many were also involved in designing facilities, participating in the complex Duffield systemic tasks, and reassuring the future in a national competition.

One particular incident stands out as an example of our environment and trust. Daron found a scanning electron microscope, something we urgently needed as a replacement to our older tools, at a small company in north-east. The asking price was $250K. I responded with a suggestion for $100K offer. Daron raised his eye-brow but didn't precipitate a long discussion that this could have easily led to and that the staff group would probably have liked to have. The company declined and Daron left the possibility of acquisition open by asking them to get back in touch in case they change their mind. A month and a half later, a suggestion for $105K arrived by phone, and in a few seconds, we had a machine that we needed badly in the new space and at a price that we could afford. Later on, Rob and Mike Guillorn orchestrated low-cost acquisition of two even better instruments from Zeiss, leveraging the strengths of CNF that all the changes brought. Lynn and others in the meanwhile were acquiring many tools to go directly in the new space - the advanced furnace banks, dry etching tools, steppers, etc., in the auctions. Our faculty community, Prof. Dieter Ast, e.g., helped in getting important donations. Lynn was managing the juggling of funds, some instruments we acquired in auctions became source of additional funds and barters. Denise Budinger had to make many runs through the purchasing and money-holding departments so that checks could be cut for the time-sensitive transactions. Lynn had the foresight to order impromptu pizzas and Chinese food when the whites of the eyes were too noticeable. This non-traditional management helped us acquire the JEOL electron-beam lithography machine that started operating without a hitch in the new space and has engendered numerous new discoveries, and achieve a laboratory whose equivalent doesn't exist anywhere. The interactions with Don Tennant at Bell Laboratories during that period were very critical to our evaluation, and may perhaps be another reason why we managed to get him to come to CNF and be part of the constant rejuvenation that any good organization needs. Melanie-Claire Mallison made sure that none of these complexities interfered with a high quality summer Research Experience for Undergraduates program in our new surroundings and our 25th anniversary celebration. Not too many have remarked that the 25th was a year late, but many have remarked that it was quite a stimulating and thoughtful event.

Continuous evaluation of who we are in our global and university context, and finding the best affordable means to be true to our principles that make the best research and graduate development happen, is possible because Cornell has individuals with a broad outlook, patience, and who are willing to commit the time needed to support and help with decisions whose impact unfolds over a long time scale. Dan Ralph and Bob Buhrman were always there to play with ideas and with the rigor required in proposal writing. Kent Fuchs always stepped in with support required from engineering administration, John Silcox and Bob Richardson guided with support for the research vision required, and Charles Kruzansky managed and helped with support from New York state.

Above all, though, it was the staff of CNF, many of whom I wish I could individually mention within the context of the zaniness of the times-people who worked nights and days, in planning, moving, acquiring and installing equipment, without flagging in our research tasks, who made CNF what it is. I thank you all for the fond memories.

Sandip Tiwari

Lester B. Knight Director 1999-2005

New Tools and Capabilities at the CNF

Ion Implanter

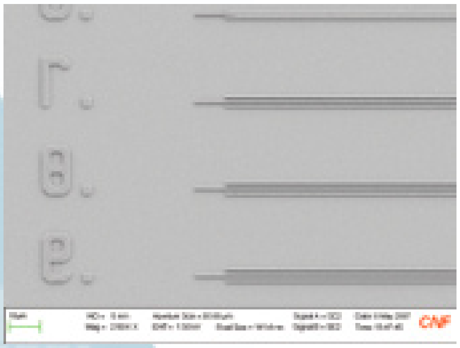
The CNF is in the process of installing an Eaton NV 6200AV Ion Implanter in its renovated space in Phillips Hall (Room P149).The system is configured for 6 inch wafers, but will be capable of implanting other sizes as well. Available energies for singly-charged species range from 5 KeV to 200KeV. The tool also has an automated cassette-to-cassette wafer handling system and a versatile end station incorporating variable wafer rotation and tilt.

Initial implant species will be boron, phosphorus, and arsenic, with the possibility of adding other gaseous sources, or an optional vaporizer source, if needed.

The system can provide typical species, doses, and energies required for current semiconductor technology, while high doses appropriate to materials science studies will require consideration of the maximum allowable sample temperature.

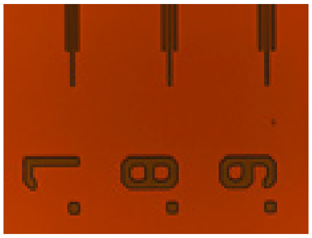
The tool installation and start-up are ongoing. For more information or training on this instrument contact staff members Paul Pelletier and Michael Skvarla.

ABM

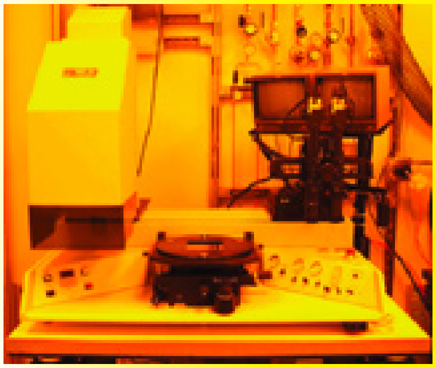


CNF recently completed the installation of a new ABM High Resolution Mask Alignment and Exposure system. This tool enhances and expands our capabilities while maintaining our currently supported processes. The flexibility of this tool is its greatest feature.

ABM's High Resolution Mask Aligner is a very versatile instrument with interchangeable light sources which allow Near-UV (405-365 nm) as well as Mid- and Deep-UV (254 nm, 220 nm) exposures in proximity (non-contact) or contact (soft & hard) modes. The exposure can cover an area 200 mm in diameter. The bottom-mount mask system accommodates masks up to 9 inches square and substrates from small chips to wafers up to 200 mm. The alignment tooling system also features an air-bearing substrate-to-mask planarization system for wedge-error compensation. The printing resolution is 0.8 µm for Near-UV and 0.4 µm for Mid-UV and Deep-UV in vacuum contact mode.



The new ABM tool is expected to replace our aging HTG aligner. It can perform all of the same functions as the HTG with the advantage of newer tooling, and also allows exposure of larger substrates. The alignment system can be used for Infra-red through-wafer alignment with the addition of special wafer chucks. For more information or training on this instrument contact staff members Garry Bordonaro or Edward Camacho.



ABM Features:

- Proximity, soft contact, and vacuum contact modes
- Substrates of any size or shape up to 200 mm diameter and 0.250 inch thick
- UV, Mid-UV, and DUV exposure modes Dual CCD Zoom Microscope alignment system, 90X to 600X
- Bottom-mounting mask holders

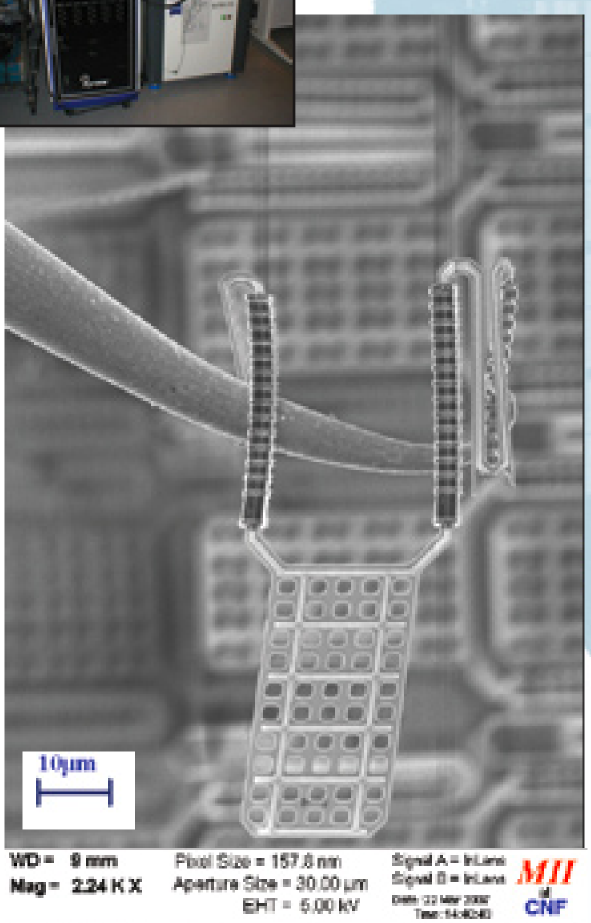
New Tools and Capabilities @ CNF

Zyvex Nanoprobes

are very cool . . .

The CNF has recently acquired a Zyvex S-100 nanomanipulation tool. This tool has been installed on the Zeiss Ultra-55 SEM and consists of four individually controlled nanoprobes. These probes can be placed with a precision of 5 nm and have a minimum tip radius of 50 nm. Combined with a Keithley 4200 semiconductor characterization system, we now have the ability to probe truly nanoscale devices, as well as driving and characterizing MEMS structures. Additionally, each individual probe has five individual input/output channels, adding the necessary flexibility to characterize even more complex devices yet to be designed.

The CNF has a long history of maximizing the potential of each tool we acquire. The Zyvex nanoprobes are a perfect fit to extend the capabilities of the lab and give researchers an additional tool to characterize even smaller devices. For more information or training on this instrument contact staff member Daron Westly.



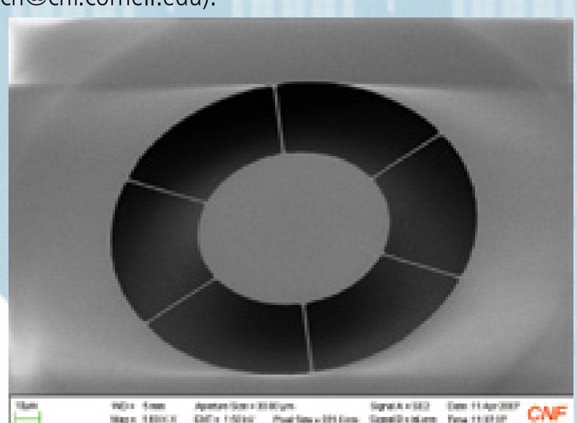
Clarkson Students Visit CNF for Hands-On Nanofabrication Experience

During the last week of spring semester, six students from Clarkson University took three days out of their busy schedules to travel to Ithaca. The objective of this trip was to participate in a CNF workshop in which the students fabricated rotational oscillators from scratch and learned nanofabrication techniques along the way. For the past three years this hands-on workshop at the CNF has been the highlight of a nanofabrication course offered at Clarkson University.

The idea for the workshop grew out of discussions between NNIN director Sandip Tiwari and Clarkson professor Cetin Cetinkaya on how NNIN resources could be used for teaching activities at other universities. The resulting workshop turned out to be a key experience for some of the seniors and graduate students who participate each year. After attending the workshop during his senior year, Justin Ricci even decided to return to the CNF to conduct MEMS research for his Master's degree under the direction of Professor Cetinkaya.

While the workshop is a lot of fun, learning the full fabrication process in three days is an intense experience. Guided by CNF staff, the students who come without practical experience, learn how to conduct the thin film deposition, lithography, and etching steps necessary to fabricate freestanding oscillators. At the end of the three days, they are rewarded with scanning electron microscopy images of the devices and measurement results that reflect some of their fabrication decisions.

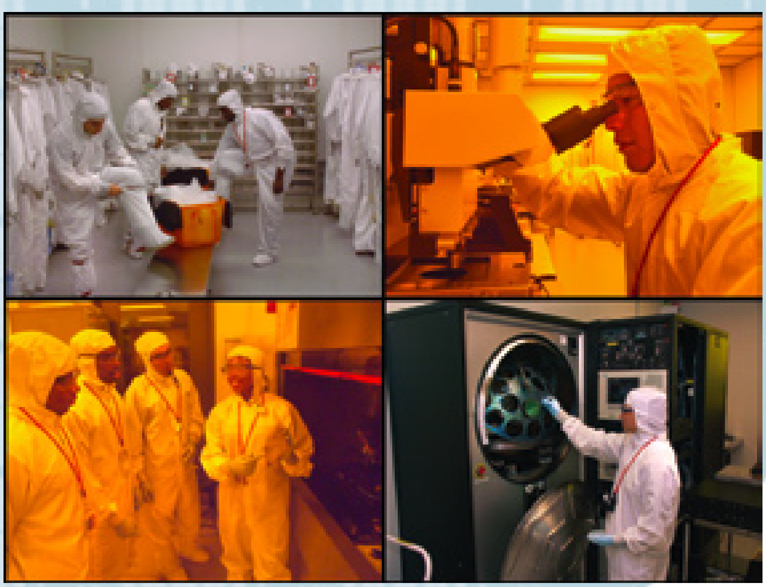
The "Clarkson workshop" has become a regular spring event at the CNF and could serve as a model for similar teaching experiences in connection with other universities. If you are interested in knowing more, please contact Dr. Mandy Esch (esch@cnf.cornell.edu).



2007 CNF REU PROGRAM

The CNF is honored to host eleven undergraduate students for a summer Research Experience for Undergraduates Program. For ten weeks our interns will dive into the world of nanotechnology and find out what hands-on research is all about. We thank the National Science Foundation, the National Nanotechnology Infrastructure Network and the Intel Foundation for making this program possible.

CNF REU Intern, 1990



2006 CNF REU Interns, Charles Harrington Photography

Mr. Kamran Afshari
From: UCLA, Electrical Engineering
Principal Investigator: Donald Tennant
Using Near Field Holography to Investigate the Wetting Properties of Nanograss

Mr. Aydin Akyurtlu
From: Virginia Tech, Electrical Engineering
Principal Investigator: Farhan Rana
Fabrication of Low-Loss Strongly-Confining GaN/AlGaN/AlN Optical Waveguides for Ultrafast Nonlinear Optoelectronic Devices

Mr. Andrew Baisch
From: Carnegie Mellon, Mechanical Engineering
Principal Investigator: David Erickson, Hod Lipson
Patterning of Electrical Circuits on Fluidic Self-Assembly Microtiles

Mr. Nathan Friez
From: Bethel College and Seminary, Applied Physics
Principal Investigator: Michelle Wang
Novel Optical Trapping Particles for Biological Experiments

Mr. Thomas Gobert
From: McNeese State University, ECE
Principal Investigator: George Malliaras
Conducting Polymer Biosensor Array Using Enzymes

Ms. Fabiola Nelson
From: NJIT, Chemical Engineering
Principal Investigator: George Malliaras
Materials Ink Jet Printing of Electronic and Photonic Structures

Mr. Brandon Noia
From: Duke University, Biomedical / ECE
Principal Investigator: Brian Kirby
Particle and Cell Transport in Coherently Patterned Micro- and Nanochannels

Ms. Sasha Perkins
From: University of Florida, MSE
Principal Investigator: Carl Batt
Microfluidic Flow Cytometery: 3-D Flow Focusing with 2-Layer Lithography

Mr. Suntrana Smyth
From: University of Alaska, Fairbanks, Physics
Principal Investigator: Sandip Tiwari
What makes the Peacock Feather Bright and Colorful?

Mr. Kylan Szeto
From: Rensselaer Polytechnic Institute, Physics
Principal Investigator: Michal Lipson
Development of Optical Fiber Packaging for Planar Lightwave Circuits by Microfabrication

Mr. Prem Vuppuluri
From: University of Portland, Mechanical Engineeriing
Principal Investigator: Derek Stewart
Thermal Transport in Nanowires

Kavli Institute at Cornell Hosts Workshop for Journalists, June 13

The Kavli Institute at Cornell will host a Journalists Workshop in Nanotechnology, Wednesday, June 13, 2007. The event is designed to educate science reporters and leads into the 30th anniversary celebration at the Cornell NanoScale Facility.

Up to forty journalists will attend the event, which provides a lecture-based primer in nanoscience and technology that is complemented with an interactive tour and hands-on experience in Duffield Hall. CNF and the Nanobiotechnology Center will lead a two-hour session with multiple stations in their clean rooms. Other experiential workshops, developed by partners in the Cornell Center for Materials Research and the Center for Nanoscale Systems, include spinning nanofibers, creating nanotubes, polymer assembly, and imaging nanoparticles in three dimensions.

A novel component of the day will be a "speed pitch" session in which journalists will interact with Cornell faculty, who will describe their current research with one slide and a three-minute pitch. The culmination of the day will be a reception and dinner with an evening program that focuses on fabrics with nano-functionality. Using the format of a "fashion show," the reporters will view fashion designs that use fabrics that incorporate antibacterial qualities. Both fun and factual, they will also learn about functional fabrics that are used as sensors or to create sophisticated air filters. We will also test whether those nano-treated pants are really stain resistant!

CNF and the Kavli Institute successfully partnered in a workshop for journalists in 2004, where participants reported that "the immersion was good," "the presenters were exceptional," and that they "loved the hands-on labs."

Cornell University
Kavli Institute at Cornell
for Nanoscale Science

Recent CNF-Related Patents, Presentations and Publications

"Absorbance Measurement of Polymers at EUV Wavelength: Correlation between experimental and theoretical calculations", Y.Kwark, J.Bravo, M.Chandhok, H.Cao, H.Deng and C.Ober, JVSTB, B 24 (4): 1822-1826 JUL-AUG 2006.

"Andreev reflection measurements of spin polarization", P. Chalsani, S.Upadhyay, O.Ozatay, and R.Buhrman, Phys. Rev. B 75, 094417 (2007).

"Biomolecule Detection Using Optical Nanostructures", H.Craighead, Invited Speaker, MEMS 2006 International Conference on Optical MEMS and their Applications, Big Sky, MT, August 21, 2006.

"Building and Patterning the Biology-Materials Interface", C.Ober, invited talk. Chemical Engineering Seminar, MIT, Cambridge, MA, Oct. 6, 2006.

"Cell Investigation of Sub-wavelength Optical Nanostructures: Plasma Membrane Studies with Single Molecule Resolution" J.Moran-Mirabal, A.Torres, K.Samiec, B.Baird and H.Craighead, Biophysical Journal, 655A-655A (2007)

"Controlling Microarray Spot Morphology with Polymer Liftoff Arrays", J.Moran-Mirabal, C.Tan, R.Orth, E.Williams, H.Craighead, and D.Lin, Analytical Chemistry, 79, 1109-1114 (2007).

"Current Progress in Lithography and High Resolution Patterning: Beyond Microelectronics", C.Ober, invited talk. BASF Research Seminar, St. Johann/Pfalz, October, 9-11, 2006.

"The Dependence of Charge Injection on Temperature, Electric Field, and Energetic Disorder in an Organic Semiconductor", T.Ng, W.Silveira, and J.Marohn, Physical Review Letters, 98, 066101 (2007).

"DNA and Protein Analysis with Nanofluidics", H.Craighead, Invited Speaker, American Physical Society, Denver, CO, March 6, 2007.

"Dynamic Characterization of Nano-electromechanical Oscillators by Atomic Force Microscopy", B.Ilic, S.Krylov, L. Bellan, and H.Craighead, Journal of Applied Physics, 101, 458-463 (2007)

"Electromechanical Resonators from Graphene Sheets", J.Bunch, A.van der Zande, S.Verbridge, I.Frank, D.Tanenbaum, J.Parpia, H.Craighead, and P.McEuen, Science 26 315: 490-493, January 2007.

"Electrospun Light-Emitting Nanofibers", J.Moran-Mirabal, J.Slinker, J.DeFranco, S.Verbridge, B.Ilic, S.Flores-Torres, H.Abruna, GMalliaras, and H.Craighead, Nano Lett.; (Letter); 7(2); 458-463; 2007.

"Functional Nanofibers Integrated with Microfabricated Devices", H.Craighead, Invited Speaker, DARPA DSRC Advancing State-of-the-Art Nanofabrication of Complex Structures W/S #2, Arlington, VA, February 16, 2007.

"Label-free immunodetection with CMOS-compatible semiconducting nanowires", E.Stern, J.Klemic, D.Routenberg, P.Wyrembak, D.Turner-Evans, A.Hamilton, D.LaVan, T.Fahmy, and M.Reed, Nature Letter 445, 519-522 (01 Feb 2007).

"Lithography and Biology: 2D and 3D Patterning for the Biology-Materials Interface", C.Ober, invited talk. Conference on Nanomaterials for Defense Applications, San Diego, CA, April 24-26, 2007.

"Lithography at Small Dimensions: Do We Need Polymers Anymore?", "Building and Patterning the Biology-Materials Interface"; C.Ober, invited talks. Bayer Polymer Engineering Lectureship, University of Akron, Akron, OH, Nov. 2-3, 2006.

"Molecular Glass Photoresists: Do We Need Polymers Anymore?", C.Ober, invited talk. Advanced Metallization Conference (AMC) 2006, San Diego, CA, October 17-19, 2006.

"Nanobiotechnology: From the Single Cell to the Single Molecule", H.Craighead, Invited Speaker, PITTCON, Chicago, IL, February 26, 2007.

"Nanofluidic Structures for Single Biomolecule Fluorescent Detection", J.T. Mannion and H.Craighead, Biopolymers, 85, 131-143 (2007).

"Nanostructures for Biomolecular Analysis", H.Craighead, Invited Speaker, MNE-2006, Barcelona, Spain, Sept. 19, 2006. Invited Speaker, CeNS Workshop, Venice International University, Venice, Italy, Sept. 26, 2006.

"Nanostructures for Molecular Manipulation and Analysis", H.Craighead, Invited Speaker, ICN+T 2006 International Conference on Nanoscience & Technology, Basel, Switzerland, August 1, 2006.

"Patterning Function and Shape For Applications: From Microelectronics to Biotechnology", C.Ober, invited talk. International Symposium Commemorating the 30th Anniversary of the Establishment of the Polymer Society of Korea, Pusan, Korea, October 11-13, 2006.

"Patterning Polymers: Applications at the Biology-Materials Interface", C.Ober, invited talk. Bayer Materials Science, Leverkusen, Germany, May 8, 2007.

"Photoacid Generators Containing Arylonium and Aryloxyperfluoroalkylsulfonate Groups for Chemically Amplified Resists", R. Ayothi, Y. Yi, H.Cao, Y. Wang, S. Putna, and C.Ober, Chem. Mater., 19(6): 1434-1444 (2007).

"Rethinking Photoresists: New Approaches to Making Very Small Structures", C.Ober, invited talk. University of North Carolina at Chapel Hill, NC, Nov. 10, 2006.

"RF MEMS Oscillator with Integrated Resistive Transduction", R.Reichenbach, M.Zalalutdinov, J.Parpia, and H.Craighead, IEEE Electron Device Letters, Vol. 27, No. 10, October 2006.

"Single DNA Molecules Stretched in Electrospun Polymer Fibers", H.Craighead, Invited Speaker, AVS Symposium-Biomaterials Interface Division, San Francisco, CA, November 16, 2006.

"Supported lipid bilayer/carbon nanotube hybrids", X.Zhou, J.Moran-Mirabal, H.Craighead, and P.McEuen, Nature Nanotechnology 2, 185-190 (25 Feb 2007).

"Tailoring the Material-Biology Interface", C.Ober, invited talk. CeNS Winter School, Mauterndorf, Austria, Feb.12-16, 2007. Ludwig Maximilian Universität, München, Germany, March 16, 2007.

"Trapping and Storage of Particles in Electroactive Microwells", B.Cordovez, D.Psaltis, and D.Erickson, Applied Physics Letters, 90, 024102 (2007).

"Understanding Thermal Integration Issues and Heat Loss Pathways in a Planar Microscale Fuel Processor: Demonstration of an Integrated Silicon Microreactor Based Methanol Steam Reformer," K.Shah and R.Besser, Journal of Power Sources, 166, 177-193 (2007).

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You will also find the NanoMeter in pdf on our web site at: http://www.cnf.cornell.edu

Cornell NanoScale Science & Technology Facility has been serving the science and engineering community since 1977, and is supported by the National Science Foundation, the NYS Office of Science, Technology & Academic Research, Cornell University, Industry, and our Users.

CNF Cornell NanoScale Science and Technology Facility

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