NanoMeter

The Newsletter for Cornell Nanofabrication Facility

Volume 12 **Summer 2001** **Number 2**

Director's Corner

In January of this year we started safety retraining of all of our users. As a result, the first few months of the year were very hectic. We tried to reduce any effect on the ongoing research, and I believe we succeeded.

Safe and disciplined operation, and careful use of the equipment, are overriding requirements for successful operation of the nanofabrication facility. Our researchers come from a variety of backgrounds - from some who are just starting on the path of research to those who have spent decades in advanced facilities, and from basic sciences to micro-electronics.

Our primary way for making sure that the research of each and every one has the best chance of success, unimpeded by other users, is to make sure that we maintain safe and disciplined operation.

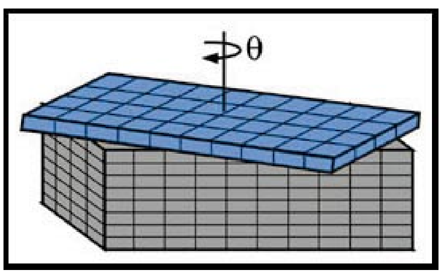
I have heard from many about the changes and I will appreciate hearing other suggestions for improvements that will help the entire research community. The subject of safety will remain a focus of our effort as we continue to build on the changes since January and make sure that an increasing number of users does not impede the success of research in our facility.

Sandip Tiwari,
Lester B. Knight Director of CNF
st222@cornell.edu

Fabrication of Nanoperiodic Surface Structures by Controlled Etching of Dislocations in Bicrystals

Rikard A. Wind, Martin J. Murtagh, Fang Mei, Yu Wang, Melissa A. Hines, and Stephen Sass. Departments of Chemistry and Materials Science and Engineering, Cornell University, Ithaca, NY 14853

Today, the smallest feature on the best microprocessor in commercial production is 150 nm. In contrast, the distance between binding sites on a human antibody is 10 nm — our smallest devices are 15 times larger than Nature's! Although impressive strides are being made in the microelectronics industry, nanofabrication at the 10 nm length scale will remain beyond the grasp of conventional nanofabrication for the foreseeable future. For the last 35 years, the performance of microelectronic devices has increased exponentially with time. This is known as "Moore's Law." The performance of lithographic tools has also increased exponentially. If this trend continues — a very questionable assumption after the year 2010 — the microelectronics industry will not reach biomolecular length scales until the year 2025.



Of course, matter can be manipulated at the atomic length scale using a scanning tunneling microscope, and a number of structures have been generated in this fashion. Unfortunately, serial technologies, such as those that require direct writing, are very slow and thus very costly. The commercialization of nanometer-scale devices will presumably require a parallel process capable of producing millions of devices at a time.

We have developed a new technique for the controlled fabrication of nanometer-scale periodic surface structures. In principle, this technique can be used to prepare features with a continuously variable spacing between 2-100 nm. (For comparison, the spacing between atoms in a silicon crystal is about 0.24 nm.) As proof of concept, we have fabricated of an array of single-crystal silicon nanostructures with a 38 nm spacing. Each nanostructure is about 25 nm in diameter — 100 atoms wide! To

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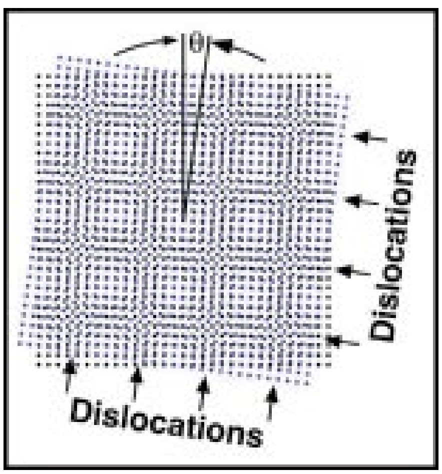
achieve structures at this very fine length scale, we make use of the inherent spacing and periodicity of atoms in a silicon lattice.

Our process is based on the production of a "twist-bonded bicrystal" which is formed by bonding a very thin silicon crystal (represented in blue) to a thick silicon crystal (represented in grey.) In this process, the two crystals are purposefully misoriented by an angle theta.

On the atomic scale, this misorientation produces a mismatch between the atoms in the top (blue) crystal and the bottom (grey) crystal. If we were able to look down on the interface between the two crystals, the atoms at the interface would resemble the sketch below.

In some regions, the atoms in the top (blue) crystal are well aligned with the atoms in the bottom (grey) crystal. These atoms form strong chemical bonds with one another. In other regions, the top and bottom atoms do not align well. These misaligned areas form a square grid or Moiré pattern as in the sketch below. Chemically speaking, these misaligned regions correspond to dislocations — lines of poor chemical bonding.



These dislocations form the basis of our new nanofabrication technique. By controlling the angle between the top and bottom crystals, we can precisely control the spacing of the dislocations.

The fabrication of the twist-bonded bicrystal is illustrated by the QuickTime movie at http://www.chem.cornell.edu/mah11/Nanofab.html. As the angle between the two crystals changes, the spacing between the dislocations also changes. Large misorientation angles correspond to small dislocation spacings and vice versa.

The table below illustrates the correlation between dislocation spacing and misorientation angle for a silicon bicrystal.

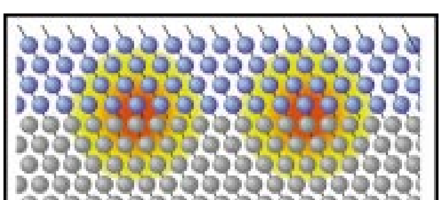
θ	Distance
0.44°	50 nm
2	11
4	5.5
8	2.8
22	1

At least in principle, this technique will allow for nanofabrication at the biological length scale. For example, to match the 10 nm spacing of the receptors on a human antibody, a twist angle of about 2 degrees would be necessary.

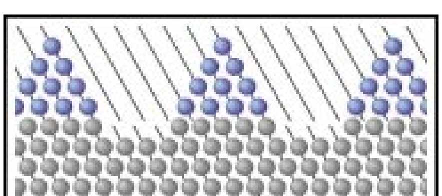
The dislocations in the twist-bonded bicrystal are buried between two crystals. To turn this buried interface into a surface structure, we make use of the high chemical reactivity of the dislocations.

Looking at the twist-bonded bicrystal in cross-section, we can see that the atomic planes in the top (blue) and bottom (grey) crystals line up in some places but not in others. The misaligned planes correspond to the dislocations, which are indicated in orange. To form a nanotextured surface, we use a specially formulated etchant that selectively attacks the dislocations. The etchant removes the dislocations and produces a surface covered with periodic "nanobumps."

After etching, the entire surface is covered by a periodic array of "nanobumps." Below, we show a nanotextured silicon surface with an average feature spacing of 38.5 nm (or 160 silicon atoms) and an average feature diameter of approximately 25 nm (or 100 silicon atoms). This spacing corresponds to a misorientation angle of 0.6 degrees. The images were taken with an atomic force microscope (AFM).



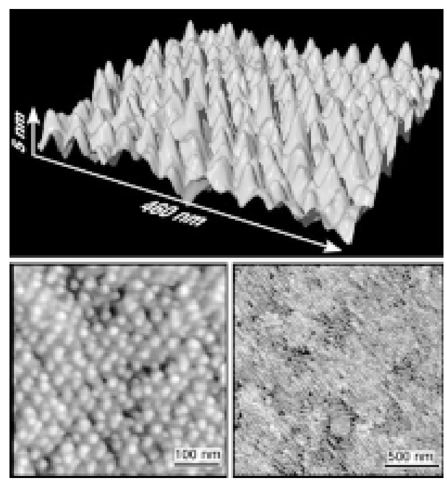
Orange shading indicates misaligned atomic planes. The misalignment leads to strained or broken chemical bonds.



Chemical etching selectively removes regions with "broken bonds" and produces nanotextured surface.

Although these nanotextured surfaces will have applications in the fields of microelectronics, magnetics, and photonics, experience has shown that the most exciting uses of nanofabrication are the ones that have yet to be imagined. What new devices await us as we learn to machine at the biomolecular length scale?

Support of this work by Philip Morris USA is gratefully acknowledged. One of the authors (M.A.H.) is a Cottrell Scholar of the Research Corporation. This work was performed in part at the Cornell Nanofabrication Facility. CNF facilities were used to precisely thin the twist-bonded bicrystal before etching. Many CNF analytical instruments were also used in the development of the process.



Three views of a nanotextured silicon surface.

Stephen Sass, professor of materials science and engineering, and Melissa Hines, associate professor of chemistry and chemical biology, display a moiré pattern representing the misalignments created by interfacing two silicon wafers. Chemically speaking, the misaligned regions correspond to lines of poor chemical bonding.

http://www.chem.cornell.edu/mah11/Nanofab.html

User Profile:

Rikard Wind

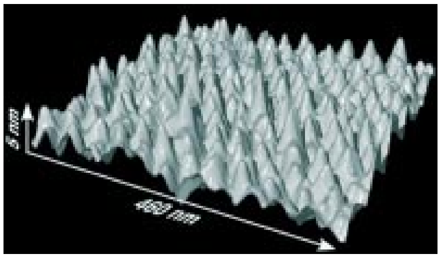


Figure Caption: AFM image of nanoperiodic silicon surface with 38 nm periodicity.

Rikard Wind is currently a Ph.D. candidate in the Department of Chemistry. Born in The Netherlands and raised in Fort Collins, Colorado, Rikard came to Cornell in 1997 after receiving his bachelor's degree from the University of Colorado at Boulder with a triple major in physics, chemistry, and biochemistry. In 2000, he received his Master's Degree in physical chemistry with a minor in materials science. Under the supervision of Prof. Melissa Hines, he has been studying wet etching of silicon.

In the past year, Rikard successfully developed the technique of fabricating nanoperiodic surfaces by etching silicon bicrystals. The challenges have been to form the bicrystals themselves and to control the etch depth. To form the bicrystal, the surfaces bonded must be clean and free of any dust particles. This requires many cleaning steps. In order to form the nanoperiodic surface, the etchant must remove all the silicon up to the interface, but not remove any more. This required optimization of the etchant composition, and etching in many small, sequential steps.

The 2001 NNUN REU Program

This year, the NNUN received over 200 applications for the 2001 NNUN REU Program — the largest number of applications yet and a testament to the success and growing popularity of our program.

We hired 42 interns total between the five sites, and the ten-week program runs from June to August, with this year's NNUN REU Convocation being held at Howard University in Washington, DC, August 8-11.

Here at CNF, we are looking forward to our fifth year as a partner in the network REU program, and of the 42 interns, 12 will be working in our cleanroom. They are listed below.

CNF REU projects range from "Construction of Thin Optical Microcuvettes" to "Integrated Antenna in Si Technology" to "Evaluation of Collagen as Molecular Filtration Material." Take a look at last year's CNF REU research accomplishments at:

http://www.cnf.cornell.edu/2000REU/2000CNFREU.html

We extend our thanks to the National Science Foundation for their unwavering support of our network and this program. And to the faculty and staff at each site whose effort and dedication provide the necessary basis for everything we do as a network, thank you.

Have a great summer!

Melanie-Claire Mallison
NNUN REU Program Coordinator

INTERN	SCHOOL AFFILIATION	FIELD OF STUDY	PI
Ms. Anna Bacon	Michigan State University	MatSciEngr	Sandip Tiwari
Mr. Philip Choi	Cornell University	EE	Edwin Kan
Mr. Matthew Daniels	Pacific Lutheran University	Physics	Jack Blakely
Ms. Caitlin Devereaux	Harvey Mudd College	Chemistry	George Malliaras
Ms. Danna Freedman	Harvard University	Chemistry	James Engstrom
Ms. Ashley Harness	Virginia Commonwealth Univ	ChemEng	Daniel Woodie
Ms. Fatou Maiga	NC State University	ChemEng	Michael Skvarla
Mr. Brian Manuel	Morehouse College	MechEngr	Michael Spencer
Ms. Meredith McElroy	University of South Carolina	ChemEng	Andreas Albrecht
Ms. Laura Moussa	Binghamton University	Chemistry	Antje Baeumner
Mr. Nagesh Rao	Rensselaer Polytechnic Institute	MatEngr/Phil	Christopher Ober
Mr. Gregory Roman	Bard College	Chemistry	Daniel Woodie

The Sixth CNF Annual Meeting & Career Fair

Thursday and Friday, September 20 and 21, 2001.

The 6th CNF Annual Meeting and Career Fair will be held on Thursday and Friday, September 20 and 21, 2001, at the Statler Hotel on Cornell campus. Join us and find out what's new in nanotechnology and see how Duffield Hall is progressing.

If you would like to attend — either as an observer or a recruiter — please contact Melanie-Claire Mallison, Corporate & Public Relations, M102 Knight Lab-CNF, Ithaca, NY, 14853. Phone: 607-255-2329, Fax: 607-255-8601 or Email: mallison@cnf.cornell.edu.

The CNF Annual Meeting and Career Fair:

- Oral and Poster Presentations allowing CNF's students and users to show you their recent research and discoveries.
- An opportunity for CNF and Cornell University engineering students to learn about your career opportunities in engineering or related industries.
- An event designed to help you illustrate the benefits of employment in your company, including internships or full-time employment, to a focused group of engineering and science students.
- Informal lunches offering one-on-one time with students and faculty members.
- A formal Thursday dinner to meet users and faculty, and hear an invited speaker.
- The opportunity for on-campus interviews with experienced nanofabricators.
- A chance to showcase your commitment to diversity by providing our students with access to recent hires, minority executives, and substantive information about entry-level positions in your organization.
- Combined with the Cornell University campus-wide Career Fair, the CNF Annual Meeting and Career Fair is the perfect addition to your recruiting efforts.

Area High Schools Visit the CNF

Odessa-Montour High School

During the month of May, students from three area high schools came to CNF for a day of discovery and fun. While Dr. Lynn Rathbun would meet with half of each group in the CNF conference room, showing them the CNF Tour Video, explaining the basic techniques of nanotechnology, the other half of the group, led by Mandy Esch, would enter the clean room and tog up for

Ithaca High School

nanofabrication demonstrations with help from CNF staff members Michael Skvarla, Garry Bordonaro, Phil Infante, Jerry Drumheller, and Karlis Musa.

At the end, we presented each of our guests with a souvenir — a 4" silicon wafer with each high school's logo etched onto the surface. With a warning that wafers are very fragile and not to be used as frisbies, we let the groups head home.

Thank you all for coming!

The Alternative Community School and their wafer design

Find all the HS visit photos at: http://www.cnf.cornell.edu/cnf/hs2001.html

The NanoMeter is published four times a year by the Cornell Nanofabrication Facility at Cornell University, Knight Laboratory, Ithaca, New York, 14853-5403. Phone: 607-255-2329. Fax: 607-255-8601.

To be added to our mailing list please email: nm@cnf.cornell.edu. And find the NanoMeter in pdf at: http://www.cnf.cornell.edu/

Your comments are welcome!

The Cornell Nanofabrication Facility, a member of the National Nanofabrication Users Network, is supported by the National Science Foundation, and has been serving the Science and Engineering Community since 1978.

From Left: Bleier, Esch, and Wright

New Staff

Alan Bleier

Alan grew up in Rochester and was a physics major at Cornell in the mid-70s. He earned a Ph.D. in Optical Sciences at the University of Arizona in Tucson, and his dissertation applied statistical pattern recognition and ultrasound to computer aided diagnosis of breast cancer.

From 1984-91, Alan was at Harvard Medical School/Brigham and Women's Hospital in Boston where he taught ultrasound physics to radiology residents and researched MRI-guided laser surgery.

In 1992, he joined a team at a radiation therapy device and software startup company near Pittsburgh. They developed the first system for Intensity-Modulated Radiation Therapy (IMRT), and it has been used to treat about 8000 patients.

IMRT is 3D lithography with megavolt x-rays inside people, with minimum feature size of about 5×10^6 nm. When the patterns from multiple radiation beams overlap, they add up to make a high dose volume that conforms closely to the tumor volume and spares nearby normal tissues. There are dosimetry and alignment issues that are similar to those in microlithography.

Last fall, Alan moved to the Ithaca Ecovillage, a cohousing neighborhood that is developing 176 acres of land on West Hill in a way that will preserve open space for future generations. His neighbor and CNF user, Doug Shire, encouraged Alan to apply for a CNF position.

Initially, Alan is learning to manage the Leica VB6 electron beam lithography tool, and eventually will guide outside users in their use of the whole lab. He enjoys learning about the technologies at CNF, and participating in the innovative research that CNF users are doing.

Mandy Esch

Mandy Esch did her undergraduate studies in biology at the Julius-Maximilians-University in Würzburg, Germany. She received a M.S. degree in biotechnology and biochemistry from the University in Würzburg in 1998, and is currently working to complete her Ph.D. in biotechnology. Her research includes the development of micro-chip biosensors for optical and electrochemical detection of DNA.

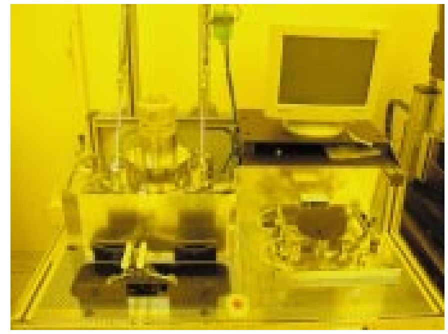
Mandy joined the CNF staff in April 2001. Her responsibility is to serve as a liaison between biomedical and biophysics researchers and the CNF's facilities. She will work directly with users in biological research to plan and implement microfabrication processes, advising them on the capabilities of CNF instrumentation.

Sam Wright

After earning a degree from a local two-year technical school, Wade "Sam" Wright started his career at Cornell in 1977. Sam worked in Nuclear Studies as part of the team building and installing their sychrotron accelerator in the tunnel. Sam then moved on to Plasma Studies as an experimental equipment operator, fabricating and installing various machines.

Last year, Sam joined the CNF technical staff as Research Equipment and Cleanroom Technician. He is involved in general maintenance of lab equipment as well as the ordering, stocking and restocking of laboratory equipment and supplies. Some of Sam's best work, though, is in helping to maintain the lab as a user friendly facility.

New Equipment



The EV520HE

The EV520HE (Hot Embosser) can be used for nanoimprint lithography including micro contact printing (MCP) and hot embossing lithography (HEL). It is capable of processing wafers up to 6 inches in diameter with top and bottom heaters capable of achieving temperatures up to 550°C. It can provide a contact force of up to 9000 lbf (40 kN) which yields a contact pressure of 800 psi (55 bar) on a 4 inch circular substrate. The embossing can be done under vacuum or with inert gases purging at pressures up to 30 psi (2 bar).

Mandy Esch is the primary contact for this new tool. She can be reached at: M104B Knight Lab, 607-255-2329, x115, esch@cnf.cornell.edu.

Recent Publications

"A Kinetic Study of the Intermetallic Compound Growth at the Interface of Ni-containing UBMs and Eutectic PbSn Solder"; P. Su, T.M. Korhonen, M.A. Korhonen and C.Y. Li, TMS Annual Mtg, Nashville, March 2000; in J. Electronic Materials (2000).

"Mixed Lamellar Films: Evolution, Commensurability Effects, and Preferential Defect Formation"; Chaikin Group, volume 33, p. 80, 2000.

"Performance Limits of AlGaN/GaN HEMT's"; Eastman Group, WOCSDICE 2000, 5/26-6/2, 2000, Aegean Sea, Greece.

"Power Limit of AlGaN/GaN HEMT's: Frequency Limits of AlGaN/GaN HEMT's"; Eastman Group, 2/20-23, 2000, Harbor Island, San Diego, CA.

"Reducing Substrate Pinning of Block Copolymer Microdomains with a Buffer Layer of Polymer Brushes"; Chaikin Group, Macromolecules, volume 33, p. 857, 2000.

"Self-Supporting Semiconducting YBaCuO Uncooled IR Detectors"; M. Almasri, D.P. Butler and Z. Celik-Butler, the 2nd TEXMEMs Workshop, Dallas, TX 16 May, 2000.

"Semiconducting YBaCuO Bolometers for Uncooled IR Detection"; D.P. Butler, M. Almasri, and Z. Celik-Butler, the 14th SPIE Annual Int'l Symposium on Aerospace/ Defense Sensing, Simulation, and Controls: Infrared Detectors and Focal Plane Arrays VI, Orlando, FL, 24-28 April, 2000.

"Semiconducting YBaCuO Microbolometers with Titanium Absorber"; A. Yaradanakul, Z. Celik-Butler, and D.P. Butler, Presented at the 2nd TEXMEMs Workshop, Dallas, TX 16 May, 2000.

"Spatial Beam Switching and Bistability in a Diode Ring Laser"; M.F. Booth, A. Schremer, J.M. Ballantyne, Appl. Phys. Lett. 76, 1095 (2000).

"Structural Properties of AlGaN/GaN Heterostructure on Si (111) Substrates Suitable for High-electron Mobility Transistors"; S. Kaiser, M. Jakob, J. Zweck, W. Gebhardt, O. Ambacher, R. Dimitrov, A.T. Schremer, J.A. Smart, and J.R. Shealy, J. Vac. Sci. Technol. B 18 (2), March/April 2000.

"A Study of L-band GaAlAs/GaAs HBT's for High Voltage RF Power"; Johansson, J. Soderstrom,. L.F. Eastman, and D.W. Woodard, Int. J. Electronics, 2000, 87, no. 4, 497-510.

"Surface Charge Dipole Template Using III-Nitride Structures"; Eastman Group, 3/6/00, DARPA, Washington, DC.

"The Polarization-induced Electron Gas in a Heterostructure"; B.K. Rridley, O. Ambacher, L. F. Eastman, Semicond. Sci. Technol. 55 (2000) 270-271.

"Two-dimensional Electron Gases Induced by Spontaneous and Piezoelectric Polarization in Undoped and Doped AlGaN/GaN Heterostructures"; O. Ambacher, B. Foutz, J. Smart, J.R. Shealy, K. Chu, N. Weimann, M. Murphy, A. Sierakowski, W.J. Schaff, and L.F. Eastman, J. of Appl. Phys. 8(1), 1 January 2000.

"Underbump Metallizations for Lead-free Solders"; T. M. Korhonen, P. Su, M. A. Korhonen, and C.Y. Li, 50th ECTC, Las Vegas, May 2000.

"YBaCuO Microbolometers for Advanced Broad-Band IR and FIR Detection"; D.P. Butler and Z. Celik-Butler, presented at Nanospace 2000 - Advancing the Human Frontier, Houston, TX, January 23-28, 2000.

A selection of publications from the past year involving CNF projects.

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