NanoMeter

The newsletter of the Cornell NanoScale Science & Technology Facility
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Director's Column

Our move into Duffield Hall provided an opportunity for vast improvements in our capabilities and instrumentation. This issue of NanoMeter brings together summary information related to these capabilities. These resources will make the coming years exciting for science and technology at Cornell.

The National Nanotechnology Infrastructure Network (NNIN) officially started functioning on March 1st of this year. We held our first workshop and debated the educational implications of the developments and the inter-disciplinary aspects of nanoscale science and engineering. Undergraduate education, with its emphasis on breadth while helping prepare for a career, and graduate education with its emphasis on depth and development of independence in pursuit of ideas and tackling problems, raise an interesting problem for this inter-disciplinary area. The workshop report articulates some of the ways these issues can be tackled. As examples, for undergraduate education, these may include modifications in course content that keep the core courses intact as well as through use of nanoscale in problems and exercises. For graduate education, these may include development of interdisciplinary courses that will have to be team-taught, and development of new interdisciplinary textbooks that utilize the new resources that computing and information infrastructure provides.

Our participation in NNIN, and our funding by NSF, brings with it a number of obligations. Acknowledgement of this support in publications that result from the work is one such obligation that we count on from our user community. We will also be collecting a network-wide research book that shows example projects and research successes. Your contribution to these helps show the national community what facilities such as CNF enable, and help attract advanced research to our facilities.

Regards,
Sandip Tiwari,
Lester B. Knight Director, CNF

This special issue of the NanoMeter, though including many of our usual features such as the *User Profile* and *Recent Publications*, specifically covers CNF-Duffield Hall Tool and Process Enhancements.

CNF moved into its new clean-room in Duffield Hall in October 2003 and the staff has worked hard to bring the new capabilities of the space to our users.

On the following pages, you'll find explanations of the equipment and processes now available. If you are interested in discussing any item further or would like to start a research project with us, please contact us at: information@cnf.cornell.edu.

CNF-Duffield Hall Tool & Process Enhancements

Step inside the CNF

The Cornell NanoScale Facility is a member of the National Nanotechnology Infrastructure Network (www.nnin.org) and is supported by:

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

Cover Photo of Duffield Hall thru the sundial, Robert Barker, University Photography

Inside wafer by Intel

CNF Cornell NanoScale Science and Technology Facility

Thin Film Deposition & Growth

LPCVD, Oxidation & PECVD Capabilities

The Cornell NanoScale Facility has expanded its furnace capacity in Duffield Hall to twenty processes from the eleven previously available in Knight Lab. The tools installed in Duffield Hall are a combination of MRL 1142 and MRL Cyclone 440 furnaces. They are four-stack units currently configured to process up to 6 inch diameter wafers and provide a 40 inch flat temperature zone. Half of the furnaces will be configured for Atmospheric Oxidation and Anneal type processes, and the remaining half will be set up as Low Pressure Chemical Vapor Deposition (LPCVD) processes.

Furnace processes currently on line or due on line soon include:

Anneals 1-4: Four different atmospheric furnaces set up to anneal various materials in N_2, 5%H_2/N_2, Ar, 5%H_2/Ar, O_2 and O_2 with HCL ambients. Anneal temperatures range from 200 to 1100°C.

Oxide: Thermal oxidation furnace providing wet pyrogenic and dry oxidation processes with or without an HCL cleaning ambient. Maximum furnace temperatures of 1100°C. Oxide thickness in the range from 100 to 10,000 Å is easily obtainable.

Nitride: LPCVD silicon nitride deposited at 775-800°C. Stiochiometric Si_3N_4 as well as low stress/silicon rich nitride recipes available. Low stress films optimized at 200 Mpa tensile stress.

LTO: LPCVD silane based silicon oxide process. Films deposited at 425°C with depositon rates in the 100 Å/minute range.

N^+/P^+ Polysilicon: LPCVD polysilicon furnace capable of depositing undoped, *in-situ* boron or phosphorus doped poly or amorphous films. Deposition temperatures range from 550 to 650°C with deposited resistivities in the 2-15 mohm-cm range for doped films.

TEOS: Tetraethylorthosilicate based LPCVD silicon oxide process. Deposition temperatures in the 650 to 750°C range.

TFT LTO 410: Diethylsilane based LPCVD silicon oxide process for TFT compatible glass substrates. Deposition temperature of 425°C.

TFT Oxide: Thermal oxidation furnace for TFT compatible glass substrates providing wet pyrogenic and dry oxidation processes with or without an HCL cleaning ambient. Maximum furnace temperatures of 1100°C. Oxide thickness in the range from 100 to 10,000 Å is easily obtainable.

TFT N+/P+ Poly: LPCVD polysilicon furnace for TFT compatible glass substrates capable of depositing undoped, *in-situ* boron or phosphorus doped poly or amorphous films. Deposition temperatures range from 550 to 650°C with deposited resistivities in the 2-15 mohm-cm range for doped films.


Furnace Banks

Eight more furnace processes are due to come on line later this year and will be set up for electronic grade device processing. These furnaces will have a more restricted material and tool compatibility policy to minimize potential contamination that can be detrimental to electronic devices. Dry and wet oxidation, oxidation with N_2O, LPCVD nitride, LPCVD high temp oxide (HTO), LPCVD undoped poly-silicon, LPCVD *in-situ* boron doped p^+ polysilicon, and LPCVD *in-situ* phosphorous doped n^+polysilicon will be available.

CNF's PECVD capability consists of two tools. A manual load tool for all types of substrates is used for oxide, nitride, and amorphous silicon deposition. The GSI Ultradep system is reserved for MOS compatible materials and is able to deposit a variety of thin films with tunable stress due to its dual frequency capability. This is essential for a broad range of MEMs applications and devices.

Deposited film capabilities include silicon oxide, silicon nitride (including low stress), silicon oxynitride of varying index of refraction, doped oxides such as PSG and BPSG, TEOS based oxide, and amorphous silicon with N and P doping.

Physical Vapor Deposition

RF/DC Magnetron Sputter Deposition

The CNF's RF/DC sputtering capabilities have been enhanced with the investigation of some new materials for photonics, MEMS and electronic applications.

The CVC-601 sputter deposition system has a cryopumped vacuum chamber which holds three magnetron sputter targets, a Kaufman Ion Source (used to sputter clean substrates), and an RF substrate bias system. The system sputters down onto a rotating platter which can hold twenty or more 4 inch wafers, as well as small pieces, or wafers up to 6 inch. The targets available are: Al, Al-1% Si, Al-1% Si-4%Cu, Cu, Co (RF), Cr, Nb, MgO, $MoSi_2$, Si (RF), SiO_2 (RF), Ta, Ti, TiW, W, WO_3.

Deposition rates are different for different targets, but range from 70 Å / min. to 500 Å / min. The system has a 3 KW RF sputter power supply, and a 3 KW DC sputter power supply, and they can be used simultaneously for co-deposition. The DC power supply is used with most of the targets, and these targets can be co-sputtered with any of the targets marked (RF). Argon, Nitrogen, and Oxygen are all available, so reactive sputtering is frequently done. Some of the films which are reactively deposited here are: Al_2O_3, AlN, CuO, SiN (RF), SiO_2 (RF), TaN, TiN, and TiO_2. Rates for these range from 8 Å / min. to 150 Å / min. Nitrogen or oxygen can also be used with the substrate bias to clean wafers, or modify reactive film growth, or nitrogen can be used in the ion beam to drive energetic nitrogen into a growing film.

Due to increased interest in piezoelectric materials for MEMs, we recently have begun to fully characterize reactively sputtered AlN films. This will be a detailed investigation of the influence of deposition parameters on the resulting piezoelectric properties.

E-Beam and Thermal Evaporation

Our evaporation capabilities consist of two CVC 4500 electron beam evaporation systems and one CHA thermal evaporation system. One system is equipped with a six pocket e-gun, while the second system has a four-pocket e-gun with three thermal sources. The line of site point source deposition characteristics of electron beam evaportation are enhanced with custom designed liftoff chucks incorporating sample tilt to 180 degrees and in plane sample rotation. CNF is continually adding new evaporation materials to meet the needs of the growing user community. For example, materials such as refractory metals (W and Ta) and dielectrics such as SiO_x have successfully been deposited.

CVC 4500

Molecular Vapor Deposition

Applied MicroStructures MVD-100

The large surface-area-to-volume ratios of surface and bulk micro-machined micro- and nano-mechanical structures can cause unintentional adhesion of device components, referred to as stiction.

Stiction occurs when restoring forces are unable to overcome interfacial forces such as capillary, van der Waals and electrostatic attractions. This results in permanent adhesion of device components to undesired surfaces. Consequently, anti-stiction coatings for micro- and nano-electromechanical systems (MEMS and NEMS, respectively) and information technology devices (e.g., hard disk storage media) have found wide spread use.

To enhance the MEMS and NEMS fabrication capabilities of the CNF, we have recently acquired an MVD-100 molecular vapor deposition system from Applied Micro-Structures. This tool is capable of depositing conformal monolayer coatings on a wide variety of substrates using a vapor phase process from liquid precursors. This technique has several advantages over similar liquid-based application processes. It provides a high degree of control of the coating environment by integrating the surface preparation and monolayer deposition reaction into a single tool.

This facilitates more uniform conformal coatings on micron and nanoscale patterns. Furthermore, the process does not utilize any solvents, a common source of contamination in liquid deposition processes. Atomic force microscope images of surfaces coated with monolayers using the vapor phase technique show a surface roughness an order of magnitude lower than monolayers produced using liquid techniques.

Applied MicroStructures MVD-100

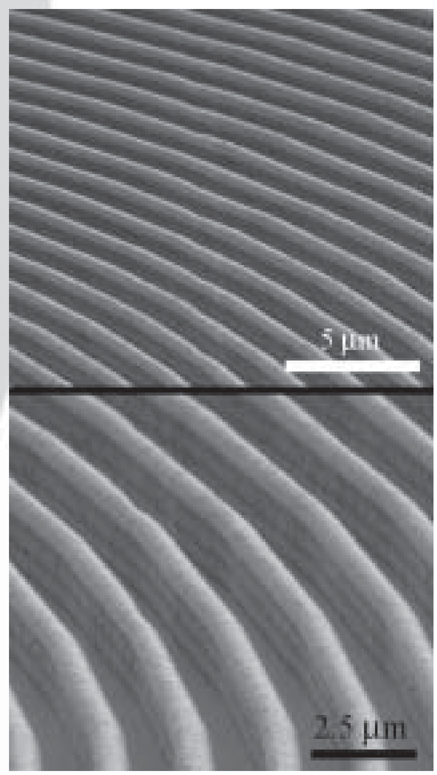
Pattern Generation

Heidelberg Instruments DWL 66

High resolution, flexible pattern generation is critical to many research projects conducted at the CNF. To meet these growing needs, we have acquired a Heidelberg Instruments DWL 66 Laser Direct Write Lithography tool. The Heidelberg will complement the capabilities of our GCA 3600F Pattern Generator in many ways. The DWL 66 is a high-resolution imaging system capable of achieving over 500,000 dpi using a 40 nm writeable address grid. A 442 nm He-Cd laser is used to perform the imaging and is capable of producing a minimum features size of 500 nm. A variety of substrates are compatible with the DWL 66 including silicon, glass, III-V semiconductors, and photomasks. Substrates up to 170 mm x 185 mm in size can be loaded into the system with minimal hardware changes.

Heidelberg DWL 66

The writing is performed using a combination of raster and scanning techniques. Substrates are mechanically moved beneath the writing lens in one axis while the beam is scanned in the transverse direction. This results in write times that are independent of the complexity or density of patterned features. Shapes that have been traditionally difficult to pattern at the CNF—circles, curves, spirals and arcs—can be written efficiently and



SEMs of a submicron circular grating patterned with the DWL 66 and etched into Si using a photoresist mask.

Heidelberg, continued

accurately using the DWL 66. This capability should be of great benefit to research in microfluidics and integrated optical devices. An example result is shown in the figures on the previous page.

The DWL 66 also provides a comprehensive set of metrology functions including line width, overlay, stitching and pattern placement measurements. Front to backside alignment is also possible for direct write applications using a video backside alignment system.

GCA 3600F Optical Pattern Generator

GCA 3600F

The facility also houses a GCA 3600F optical pattern generator. While this is an older technology, it serves as a workhorse for the creation of moderately complex masks with mask features as small as 2 mm. Users find it efficient for the generation of masks on a quick turn around basis.

Lithography

Photolithography Area

The photolithography area has derived many benefits from the move to Duffield Hall. One of the primary improvements is additional space for both the exposure tools and the facility users. The wafer steppers are now housed in more suitable isolation chambers, enhancing environmental control and tool access. The much larger stepper room allows many people to work freely without crowding. There is also a sizable space reserved for our next high-resolution litho tool.

The wafer coating room contains ten new hotplates for post-apply and post-exposure baking. Five will be designated for photoresist use only, and five will be available for use with other types of coatings. One of these is a BLE Delta 100 BM programmable temperature ramping unit for thick films, and one is a CEE Model 1100 programmable unit capable of temperatures up to 400°C. Two Blue M gravity ovens will round out the baking capabilities.

There are currently three CEE Model 100 wafer spinners in operation, each with ten programmable steps, speeds up to 6000 rpm, acceleration up to 30,000 rpm/sec., and wafer size up to 200 mm. Soon, three Karl Suss RC-8 automated wafer spinners will also be available. These units will provide automatic resist dispensing, backside rinse, and GYRSET controlled evaporation technology for exceptional uniformity.

The CEE 6000 automated wafer coater/developer now has ample space and better ventilation than before, and the manufacturer hopes to replace it with their new Talon model. CEE has placed their new spin-on planarization contact tool in the room. It can planarize wafers up to 150 mm using a UV-cured polymer, and may be used for imprint lithography as well.

Additional space allows all three contact aligners to be located in the same room as wet processing. This has reduced wafer transportion for contact lithography as compared to Knight Lab, where separate rooms were used due to the extremely crowded facilities. Transporting wafers between exposure and pre- or post-processing is also made easier by the extended yellow light area which now includes the connecting hallway.

Wet processing is much improved as well, with four wet-decks for wafer processing. Each has a center sink and two sets of nitrogen and deionized water sprayers. Another deck provides filtered hot solvent baths for mask and wafer stripping. A dump-rinse sink and spin-rinse dryer complete the cleaning process. Two Hamatech-Steag HMP 900 units will be available for single-wafer photoresist developing and cleaning;

Stepper Room

one in the stepper room and one in the contact lithography room. Another spin-rinse dryer will also be in the contact lithography room.

Mask making now has a separate area containing two dedicated Hamatech-Steag mask processing tools that will be operating soon. One of these tools, an HMP 900, will automatically develop the photoresist and/or etch the chrome layer, while the other, an HMR 900, will remove the photoresist after etching, or clean existing masks.

The new lab provides a much more stable environment for photo processing by virtue of its tightly controlled temperature and humidity, as well as cleaner air. This should allow our users much better control of their processing over longer periods of time, and better results in general. This environment, in combination with our new automated tools, should give facility users a faster path to processing success by eliminating many of the variables they have encountered in the past.

To further assist in this effort, the staff will be characterizing many of standard processes. These will include the most commonly used photoresists coated on standard substrates and exposed using standard patterns on each of the various exposure tools. Common photoresist spinning and baking processes will also be documented, as well as other coatings used in photolithography.

This information will help reduce time spent doing processes characterization for both new and experienced visitors by providing starting point and expected range parameters for operation.

Electron Beam Lithography

JEOL JBX-9300

In order to enhance the electron beam lithography (EBL) capabilities of CNF and to replace the aging EBMF 10.5, the CNF purchased a state-of-the-art JEOL JBX-9300FS EBL system. The JEOL features an advanced electron optical column allowing it to reproducibly write sub-20 nm features. An integral part of this design is the electron gun. A stable thermal field emission electron source operated at 100 keV is used to produce electron beams ranging in current from 50 pA to 50 nA and is capable of producing a minimum spot of 4 nm. The 500 μm patterning field can be addressed on a 1 nm grid using a 20-bit deflection system. This effectively eliminates patterning defects due to grid placement errors and should provide more accurate writing of nanoscale features. The system is capable of handling substrate sizes from pieces to full 300 mm wafers. In spite of its complexity, the JEOL is controlled by a user friendly UNIX-based graphical interface and compiled job language—ideal for users new to EBL.

This tool is currently one of four JEOL JBX9300-FS EBL systems in the country. However, planned upgrades to the system will establish it as one of the most advanced EBL tools in the world. In October, the scan speed will be increased from 25 MHz to 50 MHz, reducing the amount of time it takes to write a

JEOL JBX-9300FS

pattern by a factor of two. A second upgrade, to be completed in late 2004/ early 2005, will increase the maximum field size at 100 keV to 1 mm.

Leica VB6-HR

The Leica VB6-HR electron beam lithography system was tested extensively before and after the move to Duffield Hall. Its operational performance has improved with the installation of a new field emission electron source. In addition, the gun isolation valve was replaced, and the vacuum system integrity has allowed continuous operation at 100kV for the past 4 months.

Measured performance figures include:

- Room temp. variation of +/-0.16C
- 3 sigma stitching accuracy of 44 nm or better
- 3 sigma overlay accuracy of 24 nm or better
- Beam spot size less than 11 nm at 1 nA beam current
- 0.2% beam current uniformity over field at 106 nA, and < 0.1% at typical beam currents used for lithography
- Ability to write 40 nm dots 200 nm apart in ZEP7000A resist, and 15 nm lines in PMMA resist

Future improvements:

- Dry box for holders to significantly reduce pump down times
- Proximity correction software to improve dose uniformity in patterns and reduce the need for dose testing exposures
- Upgraded control workstation to improve speed of mark location and pattern transfer to pattern generator.
- Tool baselining and process control for all available e-beam resist systems

Dry Etch Enhancements

With the move into Duffield Hall complete, the CNF has added several new capabilities in the area of plasma etching. We have acquired several new pieces of equipment and are working on the development of new processes for both our existing equipment and the newly acquired systems. The new equipment consists of two Oxford PlasmaLab 80+ conventional planar reactive ion etchers and an Oxford System 100 equipped with an inductively coupled plasma source.

The Oxford PlasmaLab 80+ is capable of processing sample sizes from pieces up to 8 inch wafers. With two Oxford 80 RIE tools, both supporting the same fluorine based processes, we are now capable of making one tool MOS-compatible-only in order to better ensure process uniformity and reproducibility. One of the Oxford 80 RIEs is equipped with a tunable laser interferometric endpoint detection system, which will provide real-time in-situ process endpoint detection for large features. This will enable more precise run-to-run process control. We currently have under development a CHF_3/CF_4/Ar process for SiO_2 etching that should be capable of ~0.l µm/min etch rates with a selectivity to photoresist of ≥ 2:1.

The Oxford System 100 ICP is slated to be our advanced oxide/ dielectric etcher. It is capable of processing 4 or 6 inch whole wafers and is outfitted with the following gas chemistries: C_4F_8, C_2F_6, CHF_3, CF_4, CO_2, Ar, O_2, and N_2. It will be capable of etching SiO_2 (thermal, CVD, PECVD), quartz, fused silica, doped oxides, glasses, SiN and oxynitrides with optimized selectivities for photoresist (> 5:1), polysilicon (> 20:1), and Al (> 25:1) etch

masks. Typical oxide etch rates should exceed 0.25 µm/min with achievable aspect ratios ≥ 6:1 and smooth anisotropic sidewalls. This new ability to etch deep > 10 µm features in oxides will benefit our users working in photonics (waveguides and lenses) and MEMS (micro-fluidics and biomedical). We plan to have a CHF_3/CO_2 process for etching SiN and oxynitride selective to SiO_2 and silicon.

In total, CNF offers 12 dry etching tools supporting various materials processes. Included in these are two Plasma Therm Bosch™ ICP etch tools and a chlorine ICP system.

Further work includes plans to characterize and optimize etch processes using electron beam lithography resist materials (PMMA, co-PMMA, and ZEP) as the etch mask for oxide and nitride films.

Etch Aisle

We are in the process of fully characterizing the parameter space of the Bosch etch in the Unaxis SLR770 ICP in conjunction with RIT on a project funded by Infotonics. This will allow us to customize an etch recipe for a specific profile and application. We will also be working to improve our ICP chlorine based shallow Si etch in the Plasma-Therm SLR770. This is especially important for those applications requiring smooth anisotropic sidewalls.

Materials Modification: Doping & Activation

Ion Implantation

Our needs and requirements for ion implantation capabilities have continuously increased, especially from the device electronics community. Hence, the CNF has recently purchased an ion implanter, the Eaton 6200AV, which offers a significant improvement in capabilities over our previous tool. The 6200AV has the ability to implant sample sizes up to 6 inch wafers, at energies up to 200 KeV (400 KeV for doubly ionized species), with a fully automated operation (A) and a versatile end station (V).

The tool will be installed soon, enabling conventional Si device work as well as a variety of other implant experiments. Initial implant species offered will be Boron, Phosphorus, Arsenic, Hydrogen, and Helium.

Other species will be installed and characterized as the tool develops and projects require them. Ion Implantation is required in many standard semiconductor processes and this tool, on site at the CNF, will be a significant asset to the researchers working here.

Rapid Thermal Annealing

In addition to the re-installation of our existing RTA system (AG610C), the CNF is installing another, more modern tool—the AG/STEAG 8108.

The 610 will continue to support the wide variety of anneal processes that it offered in the former Knight Lab, including implant activation, metal annealing, oxide reflow, silicide formation, contact alloying, III-V processing, and a number of materials investigations. The tool offers a temperature range up to 1150°C, accepts a variety of materials and samples (up to 4 inch), and provides a variety of anneal environments, such as Nitrogen, Oxygen, Argon, and Forming Gas (a few %Hydrogen in Argon).

The 8108 will be configured to support a silicon device mission as one of a collection of tools offering MOS-quality processing capability on 6 inch wafers. Although the details are still developing, the 8108 will be configured to accept only clean, device-quality samples, while offering expanded temperature ranges and gas flows, including HCL and NH_3 environments, in addition to the standard offerings of N_2, O_2, Ar, and H/Ar.

The combination of a versatile, forgiving tool (the 610) with a clean, modern device tool (the 8108) will satisfy the thermal processing needs of the CNF research community.

Planarization

Chemical Mechanical Planarization (CMP)

The Strasbaugh 6EC has transitioned to Duffield Hall with expanded capabilities in terms of the number of slurries we can now utilize.

We now have slurries for:

1) Silicon oxide & nitride
2) Polysilicon
3) Single crystal silicon
4) Tungsten
5) Copper
6) Aluminum

Polishing rates vary from about 100-600 nm/min depending on the material being polished and the process used.

The tool can process whole wafers 3 inch, 100 mm, and 150 mm in diameter. The across wafer nonuniformity of the removal rate generally runs in the 5-10% range.

Strasbaugh 6EC

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Your comments are welcome!

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Supporting Processes

Biological Applications

Biology-related projects will continue to receive special support at CNF with respect to fabrication facilities and process development. Moving our wet and dry labs, dedicated to biology, from the off-site location at Langmuir lab to the second floor of Duffield Hall will enable researchers to utilize the provided equipment more efficiently.

Available will be a glove box, a fluorescence microscope, a scanning electron microscope, embossing equipment, and a parylene deposition tool. By providing these tools, CNF supports the preparation of self-assembled monolayers which are used in biosensor and other biology applications as well as in embossing processes. Conducting on-site microfluidic experiments will be more convenient due to the additional space Duffield Hall provides for state-of-the-art-recording equipment.

Our parylene tool will enable the preparation of thin polymeric layers for patterning biomolecules as well as thin coatings for implantable devices. The dry lab at the second floor in Duffield Hall also provides embossing equipment that enables embossing of microfluidic devices in polymers such as polystyrene and Zeonor plastics.

An additional advantage of the cleanroom in Duffield Hall is the close proximity to the Nanobiotechnology Center (NBTC) facility. Since CNF and NBTC both share the cleanroom, users can migrate from fabrication projects in CNF to fabrication-involving processes such as micro-contact-printing of molecules at the NBTC facilities.

Wafer Bonding & Dicing

Imprinting & Embossing

Working with materials like PDMS and SU-8 is now easier at Duffield Hall since new, permanently installed spinners are now available for these materials. The cleanroom also provides a number of hotplates at differing temperatures that makes curing SU-8 more convenient.

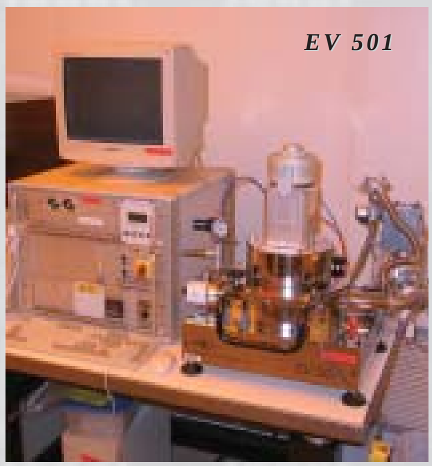
The EV 520 embossing tool enables users to experiment with Nano Imprint Lithography and micromolding on 4 inch substrates. If needed, the tooling can be adjusted so that substrate sizes other than 4 inch can be accommodated.

Electroplating

The CNF currently has three tanks for electroplating substrates. We have solutions for gold, copper, and chrome. The tanks support pieces and wafers up to 6 inch in diameter for either single-sided or double-sided plating. Deposition rates of up to 0.5 μm per minute can be achieved.

Wafer Bonding

Aligned wafer bonding continues to be available through combined use of the EV 501 bonder and EV 620 contact aligner. Superior cleaning capabilities in the new cleanroom enable superior bonding quality for direct and anodic bonding. Bonding of 4 inch substrates via intermediate polymeric layers can be conducted using the EV 520 embossing tool.



Wafer Dicing

CNF provides back-end processing with the K&S 7100 dicing saw. This advanced equipment provides dicing for a number of substrates such as silicon, quartz, pyrex glass, Gallium Arsenide, and Indium Phosphide. Special features provided are pattern recognition and automatic alignment.

CNF Cornell NanoScale Science and Technology Facility

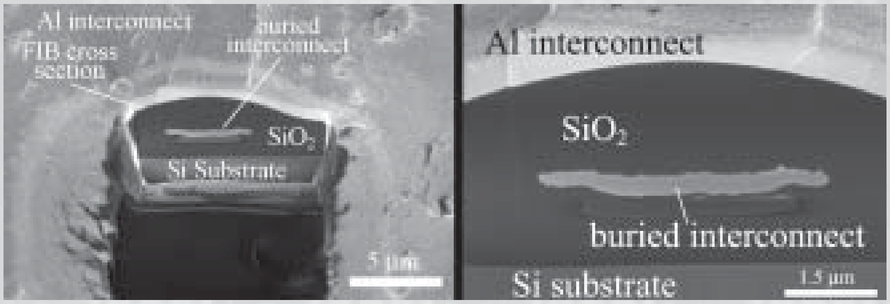
Metrology and Characterization

FEI 611 Focused Ion Beam System

Focused ion beam (FIB)-based systems provide a versatile tool for performing work at the nanoscale. They can be used to selectively remove material from substrates and to direct write insulator and metal patterns while providing a high resolution inspection system, comparable to that achieved in the scanning electron microscope. These features have made FIB instruments a staple in failure analysis labs and semiconductor foundries alike.

CNF has recently installed a donated FEI 611 FIB system. This tool uses a high brightness Ga liquid metal ion source coupled with a double lens focusing system to produce an intense beam of ions capable of being focused to a 40 nm diameter spot. It is capable of milling a variety of metals, semiconductors and insulators and depositing SiO_x and Pt. Examples of cross sections performed in the FEI 611 at CNF are shown in the following figures. In these micrographs, a multilayer interconnect structure was cross sectioned using the FIB. Following inspection in the FIB, the sample was removed and imaged in the Hitachi S-4700. This underscores the usefulness of the FEI 611 in preparing cross-sectional samples for electron microscopy.

The system is equipped with a vacuum load lock to enable rapid transfer of samples up to 8" in diameter. The tool is also equipped with a computer controlled eucentric 5-axis motorized stage. A Kleindiek micromanipulator system is also contained inside the specimen chamber to provide *in-situ* probing capabilities of samples. This micromanipulator can also be used to remove thin cross sectional samples for use in transmission electron microscopes. These samples can be produced much faster than those using traditional “cut and polish” sample preparation techniques. The micro-manipulator combined with the deposition capabilities can also be used to repair damaged MEMS structures.

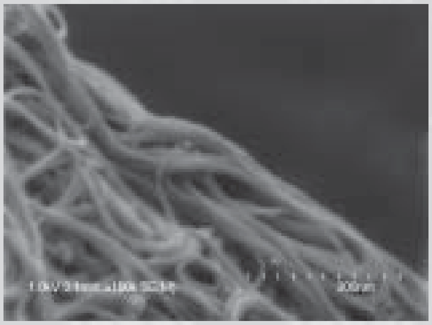


SEMs of an interconnect structure cross sectioned using the FEI 611 FIB, and close up of the structure.

Scanning Electron Microscopes (SEMs)

Shortly before CNF moved, a Hitachi S-4700 cold field emission scanning electron microscope (SEM) was purchased. Our new SEM room in Duffield Hall was specifically designed to minimize mechanical and electromagnetic noise, and as a result, features as small as a few nanometers can regularly be observed. The electron optical design of the Hitachi allows it to image at probe currents of less than 25 pA without any aperture changes. Beam energies from 500 eV to 30 keV can be used providing a wide range of operating conditions. The instrument can be tuned to image samples ranging from polymers and nanostructured materials to semiconductor devices without significantly charging the sample or causing beam induced damage. The Hitachi is also outfitted with an Oxford Instruments energy dispersive x-ray spectrum detector. This enables quantitative characterization of material composition.

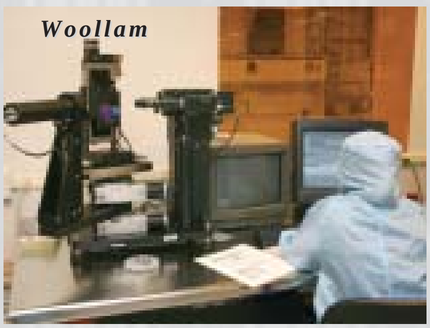
Specimen sizes from small pieces to 6" wafers can be loaded through a vacuum load lock allowing for rapid sample exchange.



SEM image of purified carbon nanotube material taken with the Hitachi S-4700.

Ellipsometry

Spectroscopic ellipsometry is a noninvasive technique that measures the changes in the polarization state Y and Δ) of light reflecting from a substrate. From these parameters, thickness as well as optical properties of thin films and bulk material are determined. Spectroscopic ellipsometry is used for characterization of all types of materials: dielectrics, semi-conductors, metals, organics, multilayers, doped films and more.



The Woollam variable angle spectroscopic ellipsometer (VASE) in the CNF has a spectral range of 193-1700 nm. The automated translation stage has 150 mm by 150 mm XY mapping capability, with automated angle range from 20-90 degrees. VASE is capable of reflected and transmitted ellipsometry.

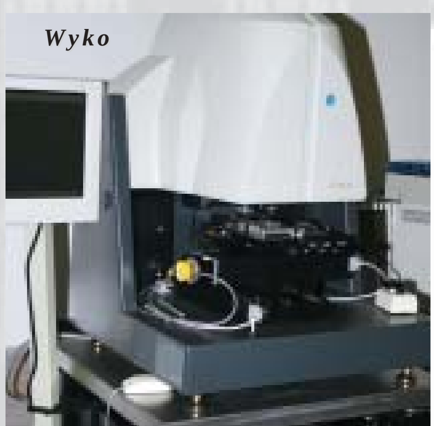
Additionally, the AutoRetarder™ provides an enhancement in the flexibility of the Woollam VASE. It allows measurement of delta from 0° to 360° with no problem areas. This is very beneficial for samples such as transparent films on transparent substrates, where it is difficult to find angles of incidence with delta away from 0° or 180°. The AutoRetarder™ also allows more complex measurements such as Anisotropic sample analysis and measurement of sample depolarization.

This instrument is perfect for characterizing optical constants, multilayer thicknesses, composition, crystallinity, surface and interfacial roughness, anisotropy/birefringence, constituent and void fractions, bandgap and electronic transitions of a vide variety of thin films and thin film miltilayers. The Woollam VASE can enhance a wide variety of exciting multidisciplinary CNF projects with significant impact on the scientific community.

Wyko NT-300HD

CNF recognized a critical need to quickly and accurately measure structures with high aspect ratios which are often produced in MEMS applications. Hence, we recently acquired a Wyko NT-300HD optical profilometer; basically an optical Atomic Force Microscope (AFM). However, rather than scanning point by point with a sharp tip, a white light interferometer is used to image a substrate. The advantage the Wyko has over an AFM is speed. Most measurements can be done is seconds and the entire sample area is imaged at once, not line by line as in an AFM.

The vertical resolution is 0.1 nm and step heights of up to 5 mm can be imaged. Because it is an optical tool, the lateral resolution is limited to around 0.5 µm. However, it complements the capabilities of the AFM and will further enhance the overall characterization capabilities of the lab, especially with high aspect ratio features (up to 30:1) produced with Deep Reactive Ion Etching.



Computing

Traditionally, CNFs computation facilities have been primarily in support of CAD and pattern conversion for lithography. CNF supports a variety of design packages including L-Edit and Mentor Graphics. With 4 different primary pattern generation tools, fast and accurate conversion of patterns from source to exposure format is critical. Primary pattern conversion is afforded by CATS (v 26) providing output to GDSII, FRE (VB6), V30 (JEOL), and DAT (PG) formats. Pattern conversion tools from the tool vendors are also available. In addition to patterns generated locally, CNF can accept externally generated patterns in GDSII format. DXF support is available if necessary.

For process and device simulation, CNF provides ANSYS 8.0 for finite element analysis, and Silvaco, a technology computer aided design (TCAD) tool capable of modeling and simulating semiconductor process flows. The ANSYS multiphysics module offers coupling of fluidic, thermal, electro-magnetic and structural elements on the sub-micron scale. Silvaco's virtual wafer fabrication technology simulation environment enables the 2-dimensional ATHENA process technology simulators and the ATLAS device technology simulators to prepare, run, optimize, and analyze semiconductor experiments to achieve optimal process recipes and device designs. Some of the above software is only available to academic users.

As a result of a computing infrastructure grant from Intel, CNF has installed a 32-node cluster of Dell dual Xenon Processor nodes. This cluster is a central part of the nanotechnology computation resource that CNF will be offering to the national research community via NNIN. Soon, a Ph.D. scientific computation associate will be joining our staff to assist users in simulations and modeling of complex nanoscale processes related to nano-particles, molecular clusters, fullerenes, etc. This combined hardware, software, and staff resource will deliver to the computational nanotechnology field the same type of staff supported high capability resource which CNF has offered to the experimental community for years.

CNF User Profile: Jami Meteer

Jami Meteer is currently a graduate student in the School of Electrical and Computer Engineering at Cornell University, and is one of 2003's co-recipients of the CNF Nellie Yeh-Poh Lin Whetten Award (together with Helena Silva). The Whetten Award recognizes an outstanding female graduate student at CNF who shows spirit, commit-ment to professional excellence, and professional and personal courtesy.

Jami received her bachelor's degree in Electrical Engineering from the University of Notre Dame (Notre Dame, IN) in 2000. Her summer activities included two REU programs (Michigan Tech and Penn State) and internships at Boeing and GM OnStar. In the summer of 1999, the NNUN REU Program at The Pennsylvania State University provided an opportunity to work on a front-side process for a piezoelectric MEMS accelerometer.

"My decision to attend graduate school was definitely motivated by my NNUN REU experience. The program gave me the chance to meet professors and graduate students who could share first-hand information about top schools and labs. With that information, making the decision to attend Cornell came naturally."

Shortly after arriving at Cornell, Jami joined Professor Edwin Kan's research group. Her main project has been the design and testing of a low temperature Si/SiGe impact diode, an electron gain structure based on localized impact ionization. The structure will eventually be integrated with a Si:As impurity-band conduction (IBC) detector. This work is done in collaboration with Professor Steve Eikenberry, formerly of Cornell's Department of Astronomy, now at University of Florida. His vision for the project is to reduce the effects of read noise in IBC detectors, which are used for space-based measurement of mid-infrared (5 to 40 µm) signals.

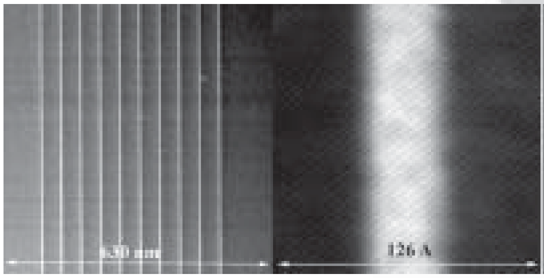
Design of the Si and SiGe layers is aimed to increase multiplication by achieving a high probability of impact ionization at each potential well. Some factors affecting multiplication include confining target electrons in the wells and providing the incident electrons with enough energy to excite the target electrons. After the layers were grown at Lawrence Semiconductor Research Lab (Tempe, AZ), Jami's work at CNF included patterning the Si/SiGe layers to form mesa diodes, passivating the surface using SiO_2, and forming electrical contacts with Al. Physical characterization using scanning transmission electron microscopy (STEM) was performed in Prof. Silcox' lab at the Cornell Center for Materials Research (Figure 1). Electronic characterization at room and cryogenic temperatures was performed at the Center for Nanoscale Science. Measurements have yielded multiplication values as high as 200 at 10K and $^{-}$10V (Figure 2).

Jami also works on using metal nanocrystals (NCs) for MOS capacitor-based asymmetric inject-ion structures. Other members of Professor Kan's group have applied metal NCs for non-volatile memory and for reduction of contact resistance. Similar to reducing contact resistance, asymmetric injection structures rely on NCs to reduce the potential barrier for injecting electrons. Since NCs are located on one side of the capacitor, the field is only reduced for one bias polarity. This project provided an opportunity for Jami's continued involvement in the NNUN REU program, this time as a mentor. During the summer of 2003, she worked with Michael Miranda, who fabricated and tested new variations of the NC injection structure.

"The main thing I learned as an REU student, and hope that Mike and others might realize, is that although working in the lab on a daily basis isn't easy, it teaches a deep appreciation for the capabilities and limits of micro- and nano-fabrication."

During the summer of 2003, Jami also helped plan and implement a project entitled "Small Robots for Cancer Detection," for the CURIE program, a week-long experience for female high school students interested in engineering.

Upon completion of Ph.D. requirements, Jami hopes to continue research at a government or military lab, and also continue participating in programs and activities that encourage young students to explore engineering.



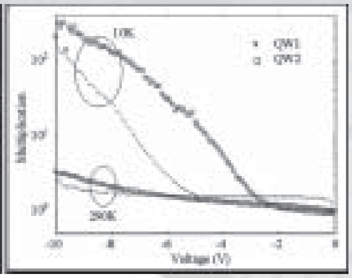


Figure 1, left & middle: STEM Dark Field Images of a) 10 Si/SiGe quantum wells and b) single SiGe quantum well. Figure 2, right: Measurements of multiplication as a function of bias at 290K and 10K for 2 quantum well designs.

Jami spends most of her play time with her 2 dogs, playing softball & tennis when it's warm, & reading; anything from 'Dune' (Herbert) to 'Kitchen Science Explained' (Wolke) & 'Reading Lolita in Tehran' (Nafisi) to 'The Elegant Universe' (Greene).

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2004 NNIN REU Program

When the team, lead by Cornell University, won the NSF's National Nanotechnology Infrastructure Network competition, they immediately honored their promise to expand the highly successful NNUN Research Experience for Undergraduates (REU) Program to include the new network sites. With that announcement, 561 applications were received in a very short period of time, to fill the seventy-two REU internships at twelve sites.

Starting in June 2004, the interns arrived at their site—their transportation and housing paid for by the program—and began their ten weeks of hands-on micro and nano exploration. Each site had their own capabilities and systems, but common expectations bound them all to provide an exciting, eye-opening, enriching summer for their undergraduates. And a $3,800 stipend.

The seventy-two interns represented 55 colleges and universities from as far and wide as the University of Puerto Rico Mayaguez to the University of Michigan, from Western Washington University to Rice University on Rhode Island. Twenty-seven women and forty-five men—3 frosh, 22 sophomores, 34 juniors, 12 1st year seniors—covered 18 different majors from biology to physics, and had such interesting minors as art history and foreign languages. But they all had in common a curiosity for nanotechnology and the inner world of research.

Working with faculty, grads and staff, the interns learned the fickle nature of research, grabbed equipment time where they could get it, ate a lot of pizza, and also managed to attend the three-day convocation at Penn State where they all presented a technical report and poster to their peers and visitors.

For all involved, it was a grand summer of successes and frustrations. Such is research and we hope their curiosity became a love for the trying. As Wilson Greatbatch, Cornellian & inventor of the pacemaker, said, "Just immerse yourself in the problem and work hard. The true reward is not in the results, but in the doing."

The 2004 NNIN REU Convocation at the Pennsylvania State University in August

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