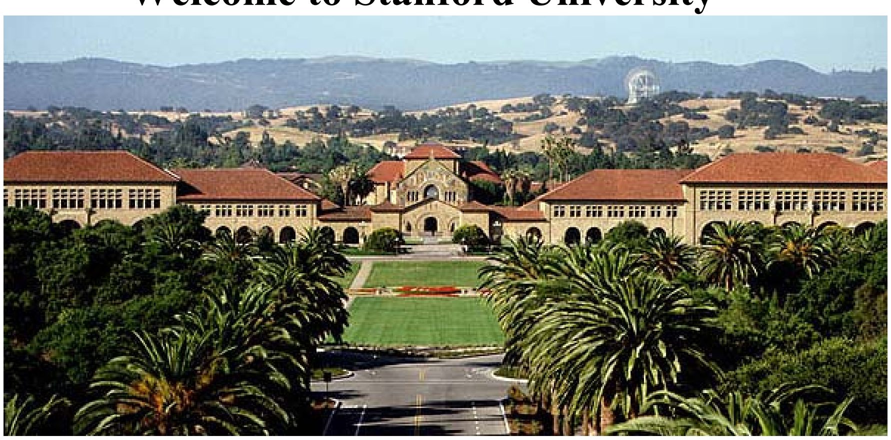
National Nanotechnology Infrastructure Network
Serving Nanoscale Science, Engineering & Technology

The 2005 NNIN Research Experience for Undergraduates Convocation

Welcome to Stanford University



2005 NNIN REU Convocation

Wednesday, August 10, 2005

Arrive at Stanford University, Stanford, CA

6:00 – 7:00 p.m. Casual Welcome Dinner – Pizza Party
Outside student dorm (680 Lomita)

Thursday, August 11, 2005

7:30 – 8:30 a.m. Registration and Continental Breakfast
Outside Skilling

8:30 – 8:45 a.m. Welcome and Announcements
Yoshio Nishi, EE Professor and SNF Director
Mike Deal, SNF REU Director
Location A - *Skilling Auditorium*

Session 1
Facilitator (Location A – *Skilling Auditorium)* – Ethan Allen
Facilitator (Location B – *Thornton 102*) – Lynn Rathbun

9:00 – 9:13 a.m. **Jock Bovington** (Location A)
Amber Brannan (Location B)

9:13 – 9:26 a.m. **Blair Brettmann** (Location A)
Caitlin Burger (Location B)

9:26 – 9:39 a.m. **Ashley Carson** (Location A)
Richard Castillo (Location B)

9:39 – 9:52 a.m. **Michael Chestnut** (Location A)
Clara Ji Hyun Cho (Location B)

9:52 – 10:05 a.m. **Eric Chu** (Location A)
Frank Cleary (Location B)

10:05 – 10:18 a.m. **Samantha Cruz** (Location A)
Michael Cullinan (Location B)

10:18– 10:35 a.m. Break

Session 2
Facilitator (Location A – *Skilling Auditorium)* – Jonshi Pang
Facilitator (Location B – *Thornton 102*) – Robert Ehrmann

10:35 – 10:48 a.m. **Minh Phuc Dao** (Location A)
Aileen Dinin (Location B)

10:48 – 11:01 a.m. **Laura Doyle** (Location A)
Nicole Escude (Location B)

11:01 – 11:14 a.m. **Hsen Dai Hsu** (Location A)
Johangel Figueroa-Montiel (Location B)

11:14 – 11:27 a.m. **Wand Gan** (Location A)
Jacob Hughey (Location B)

11:27 – 11:40 a.m. **Niusha Gutierrez** (Location A)
Matthew Harrington (Location B)

11:40 – 11:53 a.m. **Paul Harris** (Location A)
James Helton (Location B)

12:00 – 12:30 p.m. Photo Session
12:30 – 1:20 p.m. Lunch
Outside Skilling

1:20 - 1:35 Announcements (Location A - *Skilling Auditorium*)

Session 3
Facilitator (Location A – *Skilling Auditorium)* – Nancy Healy
Facilitator (Location B – *Thornton 102*) – Angela Berenstein

1:45 – 1:58 p.m. **Joshua Montague** (Location A)
Nathaniel Honsowetz (Location B)

1:58 – 2:11 p.m. **Nkemdilim Ezeife** (Location A)
Sabil Huda (Location B)

2:11 – 2:24 p.m. **Brandon Walker** (Location A)
Jodi Iwata (Location B)

2:24 – 2:37 p.m. **Jamie Jackson** (Location A)
Miktosha James (Location B)

2:37 – 2:50 p.m.	**Joy Johnson** (Location A) **Thaddeus Koehn** (Location B)
2:50 – 3:03 p.m.	**Arthur Kuehl** (Location A) **Amy Lee** (Location B)
3:03 – 3:15 p.m.	Break

Session 4
Facilitator (Location A – *Skilling Auditorium)* – Kathryn Hollar
Facilitator (Location B – *Thornton 102*) – Melanie-Claire Mallison

3:15 – 3:28 p.m.	**Cheng-Yuk Lee** (Location A) **David Light** (Location B)
3:28 – 3:41 p.m.	**Wade Luhman** (Location A) **Aaron McDaniel** (Location B)
3:41 – 3:54 p.m.	**David McIntosh** (Location A) **Stephen Meisburger** (Location B)
3:54 – 4:07 p.m.	**Andrew Melton** (Location A) **Joseph Heremans** (Location B)
4:07 – 4:20 p.m.	**Victoria Mooney** (Location A) **Que Anh Nguyen** (Location B)
4:20 – 4:33 p.m.	**Luke Niewiadomski** (Location A) **William Noderer** (Location B)
4:40 – 5:30 p.m.	Social and Ethical Issues (SEI) in Nanotechnology **Priscilla Paul, video and discussion** (*Location A* - Skilling Auditorium)
5:35 – 6:00 p.m.	Poster Setup at CISX
6:00 – 7:30 p.m.	Dinner at CISX Patio

Friday, August 12, 2005

7:30 – 8:30 a.m.	Continental Breakfast *Outside Skilling*
8:30 – 8:45 a.m	Announcements (Location A - *Skilling Auditorium*)

Session 5
Facilitator (Location A – *Skilling Auditorium)* – Amy Pinkston
Facilitator (Location B – *Thornton 102*) – Jennifer Tatham

9:00 – 9:13 a.m.	**Brian Noel** (Location A) **Virginia Noxon** (Location B)
9:13 – 9:26 a.m.	**Christopher Olson** (Location A) **Jose Pelaez** (Location B)
9:26 – 9:39 a.m.	**Calvin Peng** (Location A) **Edgar Peralta** (Location B)
9:39 – 9:52 a.m.	**Alexandra Polosukhina** (Location A) **Laralynne Przybyla** (Location B)
9:52 – 10:05 a.m.	**Marc PunKay** (Location A) **Nakul Reddy** (Location B)
10:05 – 10:18 a.m.	**Emily Rice** (Location A) **Nathan Ridling** (Location B)
10:18 – 10:35 a.m.	Break

Session 6
Facilitator (Location A – *Skilling Auditorium)* – Sandrine Martin
Facilitator (Location B – *Thornton 102*) – Ethan Allen

10:35 – 10:48 a.m.	**Idaliz Rodriguez-Datil** (Location A) **Sarah Ruch** (Location B)
10:48 – 11:01 a.m.	**Yaniv Scherson** (Location A) **Neel Shah** (Location B)
11:01 – 11:14 a.m.	**Yu-ping Shao** (Location A) **Kaylee Sill** (Location B)

11:14 – 11:27 a.m.	**Janessa Smith** (Location A) **Matthew Smith** (Location B)
11:27 – 11:40 a.m.	**Wafa Soofi** (Location A) **Joshua Symonds** (Location B)
11:40 – 11:53 a.m.	**Rachel Thompson** (Location A) **Abbie Tippie** (Location B))
12:00 – 12:50 p.m.	Lunch *Outside Skilling*
12:50 - 1:05	Announcements (Location A - *Skilling Auditorium*)

Session 7
Facilitator (Location A – *Skilling Auditorium)* – Robert Ehrmann
Facilitator (Location B – *Thornton 102*) – Nancy Healy

1:15 – 1:28 p.m.	**Winnie Tsang** (Location A) **no speaker** (Location B)
1:28 – 1:41 p.m.	**David Welch** (Location A) **Heidi Wheelwright** (Location B)
1:41 – 1:54 p.m.	**Michael White** (Location A) **Jason Winders** (Location B)
1:54 – 2:07 p.m.	**Yin Yang** (Location A) **Shelley Zieren** (Location B)
2:07 – 2:30 p.m.	Closing Comments (Location A - *Skilling Auditorium*)
2:30 – 4:00 p.m.	Poster Session (CIS and CISX)/Administrative Meeting
5:00	Bus to Huddart Park (meet in front of student dorms)
5:30 – 8:00 p.m.	Huddart Park Picnic
8:00 p.m.	Bus to Dorms

The 2005 NNIN REU Convocation
Stanford University
August 2005

Abstracts in Order of Presentation

.

Oxygen Sensing by Lateral Charge Carrier Transport in Pt Porphyrin Thin Film

Jock Bovington, Physics and Electrical Engineering, Seattle University
NINN REU Site: University of Washington Center for Nanotechnology
Dr. Babak Parviz, Electrical Engineering, University of Washington, babak@ee.washington.edu
Dr. Jianchun Dong, Electrical Engineering, University of Washington

We made an oxygen sensor based on a lateral charge carrier transport channel made of Pt-5,10,15,20-tetra(pentafluorophenyl)porphyrin - (Pt-TFPP) thin film deposited on a SiO_2/Si chip. We measured oxygen concentration by probing the current flowing across this organic thin film. To make the electrode, we patterned two interdigited electrodes separated by a 5 micron gap by photolithography followed by thermal evaporation of Cr/Au metal layers and consequent liftoff process. We formed the film on the SiO_2 surface between the electrodes by drop-casting 1% Pt-TFPP chloroform solution for 1 hr. Measurements were made on the device in a hermetic chamber with varied oxygen concentration. Compared to other conventional oxygen sensor, this new sensor can be easily integrated with current CMOS circuit by one step postprocess. By utilizing the versatility of organic synthesis, we can further engineer the molecule to improve its stability and sensitivity. Moreover, by simply replacing the conjugated metal ion in the porphyrin ring, we can alter the sensitivity spectrum of this device to sense other gases.

Fabrication and Characterization of Nanostructured Conducting Polymer Films on the Surfaces of Microfabricated Neural Prosthetic Biosensors

Amber Brannan, Applied Biology, Rose-Hulman Institute of Technology
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David Martin, Ph.D., Materials Science and Engineering, University of Michigan
milty@umich.edu
Sarah Richardson-Burns, Ph.D., Materials Science and Engineering, University of Michigan

When designing microfabricated neural prosthetic devices for implantation into the Central Nervous System (CNS) it is important to accommodate for differences in mechanical properties at the electrode/tissue interface. Biocompatibility and low electrical impedance at the interface are central to the ability of the device to function. In previous studies from our lab, the conducting polymer poly(3,4-ethylenediocythiophene) (PEDOT) was electrochemically deposited on neural microelectrodes in the presence of cross-linked hydrogels to produce soft, low impedance materials with the potential to improve device performance after implantation. The focus of this project is to evaluate the role of hydrogel concentration and cross-linking on the structure and properties of molecularly-thin PEDOT networks deposited in the hydrogels, alginate and poly(vinylalcohol) (PVA). The electrical properties of these PEDOT networks were studied using electrochemical impedance spectroscopy (EIS) and cyclic voltammetry (CV). The EIS results show that a 60 minute deposition of PEDOT in cross-linked 1% PVA gave the lowest impedance at the CNS-relevant frequency of 1 kHz. CV results indicate that this PEDOT structure has the greatest charge capacity. Surface area quantification supports the idea that the lowest impedance and highest charge capacity corresponds to the largest PEDOT network.

Self-Assembly of Nanofabricated Colloids

Blair Brettmann, Chemical Engineering, University of Texas at Austin
NNIN REU Site: Cornell University
Abraham Stroock, Chemical Engineering, Cornell University,: ads10@cornell.edu
Stephane Badaire, Joseph Woody, Chemical Engineering, Cornell University

Colloidal dispersions are made of solid particles with sizing between 10nm and 1μm in solution. These particles can self-assemble into crystals with lattice spacing on the order of the wavelength of visible light, and thus are useful in the field of optics. Currently, most scientists are working with spherical colloid particles, but we believe that cylindrical particles will also form intriguing crystals. We use photolithography to define cylindrical objects on the order of 1 μm out of silicon dioxide, and then release them from the substrate, forming a colloidal dispersion. Within the dispersion, the cylindrical particles will interact by shape-specific depletion interactions, forming structures that will be studied, and hopefully used in photonics applications. In this study we fabricated cylindrical colloid particles from silicon dioxide. We chose silicon dioxide for its well-known properties. We first used photolithography techniques to create cylinders of positive photoresist, which we used as a mask to plasma etch through a layer of silicon dioxide on a sacrificial substrate. In order to study the cylinders as freely dispersed colloidal particles, we released them from the substrate using phosphoric acid. We will study these particles in capillaries under various conditions to determine the structures formed.

Fabrication of Nanomechanical Oscillators for Chemical and Biological Sensing

Caitlin Burger, Physics/Mathematics, Shippensburg University
REU Site: Cornell University
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Cantilevers are commonly used as transduction mechanisms for sensing purposes. For the main focus of this project, the nanomechanical oscillators will be used to detect chemical and biological species. In this work, devices composed of silicon nitride suspended above silicon are fabricated and tested. The cantilevers are fabricated using both optical lithography and electron-beam lithography methods. The widths of the devices range in size from 1 micron to 1.5 microns and the lengths range in size from 6 microns to 12 microns. Gold dots are used to achieve adhesion via thiolate self-assembly. Interferometry is used to measure the frequency of oscillation; vacuum encapsulation is used to achieve a high quality factor. The objective of this research is to detect a difference in resonant frequency before and after the addition of the attached mass; a change will give information about the adhered mass. The basic model can be related to the equations involved in Hook's law regarding a rectangular leaf spring.

Polymer-filled Optical Through-Wafer Interconnects for Heterogeneous 3-D Microsystem Integration

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Kevin Martin, Georgia Institute of Technology, kevin.martin@mirc.gatech.edu
Hiren Thacker, Electrical and Computer Engineering, Georgia Institute of Technology

Interconnects are the primary limiter to improving the performance of integrated circuits. Three-dimensional integration has the potential to alleviate this problem, through shortening the length of the interconnects. In addition, there is growing interest in building heterogeneous microsystems with combined electrical and optical functionality. The focus of this project is the fabrication and demonstration of polymer-filled optical through-wafer interconnects as a building block for heterogeneous 3-D microsystems. 55µm-wide vias were etched in 400um thick silicon wafers and filled with Avatrel™ 2580-20 polymer. Filling the vias with polymer helps create index-matched optical transmission paths. The polymer was characterized to have an optical loss of ~3dB/cm . Polishing was used to reduce surface roughness of the polymer-filled vias to under 1µm. Successful transmission of optical signals through the interconnects was demonstrated. The polymer-filled vertical optical interconnects, when combined with other optical elements, and fabricated alongside vertical electrical interconnects can provide an exceptional heterogeneous 3-D interconnect solution.

Characterization of Photo Electro-Chemical Etching on SiC substrate for Pressure Sensor Diaphragm Design

Richard A. Castillo, Mechanical & Materials Engr. Dept., Florida International University
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James Griffin, Howard Nanoscale Science and Engineering Facility

PEC (Photo Electro Chemical Etching) is a method of bulk micromachining in which a material is electrochemically etched using UV radiation and an electrolyte etching solution (Hydrofluoric Acid (Hf), Potassium Hydroxide (KOH). This will be the targeted method for the machining process of Silicon Carbide (SiC) in order to create a defined structure to be used for pressure sensing. PEC has been chosen since the process generates highly anisotropic, selective and very smooth etch morphologies, perfect for pressure sensor diaphragm design. This project will be limited to (1) characterizing the etching rates of such processes including the introduction of different etching solutions/electrolytes which will enhance not only the etching process but the surface morphology as well, (2) and study the interaction & behavior of defect densities and micro pipe presence during SiC etching. The quality of the PEC process is very dependent on the amount/densities of such defects within the SiC material. The proposed sensor has been chosen to be part of a pressure sensing device that could be implanted within the human body. Because SiC is a wide band gap material, is chemically inert and possesses a very high Young's modulus, it is an ideal material that can withstand the temperature, reactivity and stresses within the aortic region of the human heart.

Characterization of Nano-Filtration (NF) Membranes

Michael Chestnut II, Computer and Electrical Engineer, North Carolina State University
NNIN REU Site: Howard University
Dr. Kimberly Jones, Department of Civil Engineering, Howard University
Jermey Mattews, Department of Civil Engineering, Howard University

The goal of this research was to characterize nanofiltration (NF) membranes by measuring the membrane charge, the surface roughness, and the membrane pore size. Characterization of these physical-chemical characteristics of the membranes will help to determine the suitability of these membranes for specific biological applications such as separation of DNA from heme or targeted protein-protein separations. The membrane flux and rejection levels were also examined, however the particular focus of this paper is charge, roughness and pore size of the membrane. The equipment employed to study the charge of the membrane is the Electro Kinetic Analyzer, which uses a streaming potential measurement to calculate the zeta potential of the NF membranes. The overall surface morphology was examined using an Atomic Force Microscope with a liquid cell. This paper also provides background information on the applications and systems that use these membranes. There is good agreement between theoretical and experimental results for some of the characteristics.

Fabrication and Characterization of Nanoscale InN Sensors using Anodized Aluminum Oxide Etch Mask

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Dr. Ho-Young Cha, Electrical Engineering, Cornell University

InN has some advantages over other semiconductor materials in sensor applications because of high surface electron concentrations. The source of electrons is not known, but is likely to involve surface defect states as donors. In this project, we have patterned nanometer-size holes on InN thin films to increase the surface area and to improve electrochemical sensitivity. A patterning process involving porous Anodized Aluminum Oxide (AAO) etch mask and ECR dry etch was developed in this project. Holes with 100-200nm in diameter and 100nm in depth have been achieved using AAO process. InN sensor devices were also fabricated using e-beam lithography and UV optical lithography for comparison. UV nanoimprint lithography was also investigated as a possible patterning technique. Preliminary optical measurements have indicated increased surface electron concentrations, possibly due to creation of donor states from the plasma exposure in the ECR dry etch step. IV characteristics and electrochemical sensitivities will be measured on these devices.

A Microfluidic System for the Assembly and Culture of Tumor Spheroids

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REU Mentors: Tushar Bansal, Electrical Engineering, University of Michigan
Mikhail Pinelis, Electrical Engineering, University of Michigan

The purpose of this project was to fabricate a microfluidic device in which multicellular tumor spheroids can be grown to a specific size. Tumor spheroids can mimic the in vivo geometry and behavior of certain tumor types. Multicellular tumor spheroids have been used as an in vitro model for studying tumor cell response to therapy. Spheroidal cell studies have now progressed to the study of differentiation, invasion, and other basic biological mechanisms. To assemble the tumor spheroids, tumor cells are passed through fabricated microchannels and trapped by perforated, semicircular wells within these channels. The arrays of embedded wells had diameters ranging from 200 to 800 µm. The channels were made by pouring polydimethylsiloxane (PDMS) over an SU-8 2050 mold patterned using conventional lithographic techniques. SU-8 was used because it allows fabrication of structures with thicknesses greater than 100 µm. PDMS was chosen for its bio-compatibility, ease of use, and low cost of fabrication. The PDMS was baked for 24 hours at 80°C to ensure maximum cross-linking and Young's modulus. The PDMS chip was bonded to a glass side by exposing both to an oxygen plasma. To improve the PDMS-glass bond, the assembled device was baked for 30 minutes at 115°C.

Microfluidic Devices for Biological Applications

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David Wood, Physics, University of California, Santa Barbara

In recent years much interest has been generated in devices in which fluid is moved through micrometer scale channels. These so called microfluidic devices show great promise in their application to biology and medicine. One possible application is a cheap, disposable cell sorting device that requires only small sample sizes. Such a device would be very useful in immunology and cancer research as current cell sorting technology has none of these desirable properties. One key problem in creating a microfluidic cell sorter is that the fluid flow must be switched between two or more collection points. By fabricating a microfluidic device in which fluid flow is switched by the application of an electric field an important element of a microfluidic cell sorter is completed. We have investigated the fabrication and use of such a device made out of polydimethylsiloxane (PDMS), a silicon elastomer. We present our fabrication process as well as data on device performance. We also present data from simulations of a bead in a microfluidic channel as it moves over a coplanar waveguide, a promising scheme for the detection of cells.

Synthesis of α-Iron Oxide (Hematite) by Sol-Gel Dip-Coating Processes

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The push for a hydrogen economy has created a need for more efficient methods of not only the use and storage of hydrogen, but more fundamentally the production of the fuel. Using renewable resources for the production of hydrogen by photoelectrolysis is attractive as a sustainable, non-polluting, long-term contribution to hydrogen as an energy source. However, this process is mainly limited by the efficiency of the materials used for the photoelectrochemical production of hydrogen. Hematite, α-Fe_2O_3, has some of the desired properties of the semiconductor to be used in this process, both corrosion resistance as well as an ability to absorb around 40% of the solar spectrum, however, charge transport can be inefficient, and defects present can be detrimental. By using a Sol-Gel dip-coating methodology we can create hematite electrodes at a very low cost and study the effects of dopants to overcome the unfavorable properties and defects that are inherent in this material. Further the Sol-Gel synthesis method can be implemented in a combinatorial chemistry fashion which will expedite the synthesis of improved iron oxide photocatalysts for hydrogen production as well as increase the viability of the screening and synthesis of these materials for future industrial and scientific uses.

Porous Nanostructured Titania

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The excellent electrical and mechanical properties of Nanostructured Titania (NST) make it an ideal material for many different applications including dye sensitized solar cells (DSSC). While DSSCs are cheaper to manufacture than silicon-based cells, they are also less efficient. The efficiency of the DSSCs depends on how well the sensitizing dye coats the cell and how well the electron recombination source infiltrates into the NST. Therefore, the structure of the NST has a great effect on the efficiency of the cell. Traditional NST production techniques, such as sol-gel processing, screen-printing, and reactive sputtering, all result in the formation of cracks throughout the NST and do not allow for large variations in pore size. However, we have developed a simple technique that is compatible with current microelectronic manufacturing practices and produces crack-free NST with a sponge-like structure. It is proposed that control over the porous nature of this NST will allow for better dye sensitization and yield more efficient solar cells. In order to optimize such devices, an investigation was preformed to determine what variables affect the pore size and surface area of the NST. Overall, this knowledge should help enable the production of better DSSCs and other NST based devices.

Suspended Langmuir-Blodgett Germanium Nanowire Film for Surround Gate Transistor

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Qian Wang, Chemistry, Stanford University

Transistors with surround gate can carry more current and allow for higher gate efficiency. By suspending a thin Langmuir-Blodgett (LB) film of Germanium nanowires across a trench between the source and drain, we can effectively implement a surround gate design for our transistor. In this project, we will fabricate the trenches using e-beam lithography. Next, we will transfer the film and pattern the sources and drains. Then, we will use the liftoff process to deposit High-K dielectric materials (HfO) with the Atomic Layer Deposition method. Lastly, we will use sputtering to deposit the metal for the gates. From SEM images, we have confirmed that most nanowires can stay suspended across the trench after the liftoff process for the drain and source metal. However, we still need to optimize our processes and film quality to fabricate cleaner devices with good contact between the metal and wires. When DC probing confirms that enough current is passing through the suspended film, we will proceed to the High-K and gate metal sputtering. After measuring the electrical properties of the finished device, we can gain a better understanding of the surround gate design in thin film nanowires transistors.

The Development of a New Method to Monitor the Activity of Neuronal Networks Using Microelectronic Chips

Aileen Dinin, Chemical and Biomedical Engineering, Carnegie Mellon University
REU Site: Pennsylvania State University
Jian Xu, Osama O. Awadelkarim, Engineering Science and Mechanics, Pennsylvania State University, jianxu@psu.edu, ooaesm@engr.psu.edu

It has been already proven that microelectronic chips can monitor neuronal networks in a planar configuration, that is, with only one surface of the cell contacting the electrodes. The focus of this paper is the fabrication and testing of a device that would allow for three-dimensional contact between the neuronal cells and the electrodes, yielding a stronger signal from the cells. First, as a feasibility test, wells were etched in silicon and glass substrates and cell growth was tested. Once cell growth was deemed sufficient, process details were determined from a rough outline and then the chips were produced. After several trials, a chip was constructed with gold electrodes and contact plates and a single large well for the cells, which could contain both cells and medium. Wells were constructed using benzocyclobutene, a spin-on dielectric, and were approximately 5 μm deep. The action potentials of the neuronal cells will be monitored with the fabricated chips of microelectrode arrays.

Characterization of Polymer Properties for Use as Pillar-Like Electrical-Optical I/O Interconnects

Laura Doyle, Biomedical Engineering, Johns Hopkins University
NNIN REU Site: Microelectronics Research Center, Georgia Tech
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Ate He, Chemical Engineering, Georgia Tech

Polynorbornene-based polymers have long been considered desirable materials for electrical-optical interconnects due to their low dielectric constants, high indices of refraction, low elastic moduli, and photodefinability. In recent developments, polymer pillars have been coupled with metallic conductors to transmit electrical and optical signals. These more complicated structures require precisely constructed features. For optical interconnects, the sidewalls of the pillars should be smooth to reduce scattering and subsequent optical losses. For electrical applications, interior cavities should be cleanly developed down to the underlying surface to ensure reliable electrical contacts. Choosing an appropriate polymer formula is essential to obtain these results. Each formula yields different results in fabrication, so preliminary tests are necessary to determine the optimal material for each application.Three different formulas of the polynorbornene polymer Avatrel were tested under different exposure doses, post exposure bake temperatures, and durations. The formula that developed best overall with respect to structural perpendicularity, smoothness, depth of interior development, and top surface flatness was then further tested in fabrication applications. Through these fabrication processes, it was shown that the chosen formula can be used to create smooth 130µm tall pillars for optical uses and filled with copper for solid electrical connections between wafers.

Optimizing Passivation Methods for Type-II InAs/GaSb Superlattice Infrared Photodetectors

Nicole Escudé, Physical Science emphasis Chemistry, Biola University
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Sanjay Krishna, Electrical Engineering, University of New Mexico, skrishna@chtm.unm.edu
Elena Plis, Electrical Engineering, University of New Mexico

High-temperature superlattice (SL) infrared (IR) photodetectors have many potential applications in thermal imaging, including optical remote sensing, night-vision, fire control, and point sensors for monitoring automobile emissions. The SL structure, comprised of alternating layers of III-V semiconductor materials, creates a p-i-n junction, producing a basic diode that responds to incoming IR radiation. Surface states, observed on the superlattice surface upon termination of crystal growth, trap the charge carriers and greatly decrease detector performance. Passivating the photodetectors by sulfidization has repeatedly been shown to reduce surface states, thus reducing dark current density and increasing photocurrent density. This indicates improved device performance due to the applied surface passivation. No optimized method for passivating III/V SLs has yet been established. The two-fold objective of this project is to: (1) compare the efficacy of aqueous and non-aqueous sulfur-based passivation solutions, and (2) find the most effective recipe and time of application for a chosen solution on type-II InAs/GaSb superlattice photodetectors. Effectiveness will be determined based on the analysis of basic detector figures of merit, namely, responsivity, specific detectivity, dynamic impedance-area product at zero bias, and background limited infrared photon (BLIP) temperature extracted from the spectral response, dark current, and photocurrent measurements.

FIB and TEM Analysis of Nanoscale Thin Films

Derek Hsen Dai Hsu, Materials Science and Engineering, Northwestern University
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Robert Sinclair, Materials Science and Engineering, Stanford University
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Richard Chin, Materials Science and Engineering, Stanford University

Valued in industry for its increased strength in wire form, pearlitic steel has a lamellar microstructure of alternating ferrite (α-Fe) and cementite (Fe_3C) phases. Consequently, modeling the system by multilayer deposition and observing changes in periodicity and composition may reveal different applications. Using sputter deposition, thin film samples of alternating iron and carbon layers (with 0.1-5 nm periodicity) have been made to duplicate the microstructure. In this study, we use the dual-beam Focused Ion Beam (FIB)/Scanning Electron Microscope (SEM) to prepare cross-section Transmission Electron Microscope (TEM) samples. Then, we examine the structural changes of the Fe/C thin films in the temperature range of 350-450°C by using *in situ* TEM to view the behavior of the system during the annealing process. This will illuminate how small changes in Fe/C thin films compositions can result in immense differences in structure and hence, its properties.

Model Micro-channels for the Study of Aerobic, Nano-porous Biocatalytic Latex Coatings

Johangel M. Figueroa, Industrial Biotechnology, University of Puerto Rico, Mayagüez
REU Site: University of Minnesota, Twin Cities
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Embedding bacteria in a nano-porous, self-assembled polymer coating would create highly reactive biocatalysts useful in micro-channel reactors. Our model system is a ~ 65 µm thick nano-porous acrylate/vinyl acetate latex coating containing the bacterium *Gluconobacter oxydans*. *G. oxydans* is a rod shaped obligate aerobe which can carry out many oxidations, such as D-sorbitol to L-sorbose, using membrane bound dehydrogenases. This oxidation is non-growth associated, oxygen dependant and can be measured using HPLC. Bioconversion of D-sorbitol to L-sorbose was initially studied using 2.5 cm^2 latex coatings in a non-growth media. A high reaction rate per surface area of coating was observed. Model micro-reactor channels (~ 500 µm to 1000 µm deep x 12 cm long) where designed. Microscopic images of a nano-porous coating in ~ 450 µm wide channels where obtained. A large micro-channel, 10 mm wide, where coated strips of *G. oxydans* can be tested was developed in order to measure the reaction rates accurately with HPLC. The reaction rates obtained in this larger channel, with a two-phase bubbly slug flow, will help us predict biocatalytic activity of *G. oxydans* in < 500 µm micro-channels, and aid us in the engineering of nano-porous biocatalytic coatings for micro-channel bioreactors.

Electrical, Optical, and Thermofluidic Wafer-Level Chip I/O Interconnects Enabled by Nano/Microimprint Lithography

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The increasing demands of silicon microprocessor technology on power delivery (>400A), chip input/output (I/O) bandwidth (>50 Tbs), and heat removal (200W/cm^2), have affected a need for the development of compatible electrical, optical and thermofluidic chip I/O interconnections (or multimodal I/O). The goal of this project is to develop low cost wafer-level batch fabrication techniques for multimodal I/O interconnections using nano/microimprint lithography technology. The fabrication of these structures involves spin coating and soft baking a thick, photodefinable polymer film, subsequently transforming the surface topology of the film using nano/microimprinting, and finally UV irradiation through a pattered mask, followed by hard baking and spray developing. General fabrication techniques for nano/microimprinting have been developed, both in template fabrication, with features as deep as 25 μm, and in demolding, for which various anti-adhesion layers have been tested. We have successfully produced the following unique interconnect structures: (1) surface-normal optical waveguides terminating in mirrored tips to be used as dual-mode pins, transmitting electrical and optical signals simultaneously, (2) board level, funnel-shaped sockets to hold and align dual-mode polymer pins, and (3) thermofluidic back-side heat sinks compatible with dual-mode pins. The development of these processes has also introduced the possibility of using nano/microimprint lithography in further applications.

New Techniques for Generating Core/Shell Nanoparticles

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The outstanding potential of core/shell nanoparticles stems in large part from the ability to obtain structures with combinations of properties that neither individual material possesses. This research focused on the synthesis of a gold shell on spherical silica nanoparticles. Although spherical gold nanoparticles generally have a surface plasmon resonance at a wavelength of about 520 nm, a core/shell configuration offers a more highly tunable plasmon wavelength depending on the thickness of the shell, the diameter of the core, and the ratio between the two. While silica core/ gold shell nanoparticles have been fabricated previously by chemical reduction of a gold salt, our work attempted to generate these structures by photochemical reduction and by nanosphere lithography. These techniques have the possibility of providing finer control of the properties of the gold shell compared to the chemical reduction method. Optical spectroscopy and electron microscopy were used in the characterization of these nanoshells.

Hydrogen Passivation of Photodiodes

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The objective of this project is to investigate and study the effects that Hydrogen passivation has on the dark current of p-i-n type photodiodes. Hydrogen has been extensively used in semiconductor growth and processing to pacify defects in the material. In this work, I have investigated the effects of hydrogen on the I-V characteristics of p-i-n photodiodes with a circular diameter that varies between 40 and 160µm. These devices were grown using Molecular Beam Epitaxy and their I-V characteristics at room temperature were obtained using a micromanipulator and a wave analyzer HP4156B. A hydrogen plasma was created using a Reactive Ion Etcher, using 10 minute runs, varying the recipe power, flowrate and pressure variables to find the best parameters with which the dark current in the device decreases. After the recipe was found, the time was varied. The results indicate that while longer exposures provides some defect passivation on the photodiodes, decreasing the dark current, other variations of the hydrogen plasma can have adverse effects on the devices.

Experimental Study of Nanoparticle Penetration Through Various Filter Media

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As nanotechnology becomes a commonplace in our society, the exposure to nanoparticles is on the rise. Research suggests that the inhalation of nanoparticles may cause a range of health risks. In this particular study, we are investigating the performance of nanoparticle filtration/penetration of four standard filters and seven specialized filters. Silver nanoparticles are used for testing, and impact the filters at 5.3 cm/s, a typical face velocity of the face masks worn by humans. Higher face velocities are tested as well. A monodisperse aerosol is created, using a nanometer aerosol differential mobility analyzer (Nano-DMA), in order to test penetration as a function of particle size, which ranges from three to twenty nanometers. Particles are counted upstream and downstream of the filters using a TSI model Ultra-fine Condensation Particle Counter, UCPC. The pressure drop across the filter is also measured for a filter quality comparison between the different filters. Results from these tests are to be used for the mathematical modeling of filter penetration as well as for analysis in the attempt to create a better filter medium.

Spin Dependent Transport

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The research focus is on spin polarized transport through thin polymer spacers using manganite electrodes in lithographically patterned nanostructures. The giant magnetoresistance (GMR) effect can be observed in magnetic thin films, which are composed of ferromagnetic layers and nonmagnetic (spacer) material. The ferromagnetic material being used in our research is La0.7Sr0.3MnO3 (LSMO), which is nearly half metallic with very high spin polarization at Fermi Surface. When the ferromagnetic layers are parallel they have a low resistance as opposed to when they are antiparallel. With an applied magnetic field the direction of the magnetization can be altered. The goal of this project is to have a coherent spin transport across an ether polymer spacer material through spin injections and to observe the GMR effect.

Laser Direct Write Grayscale Photolithography

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Laser direct write photolithography is typically used to make 2D patterns on photoresist coated substrates. The intensity of the beam is chosen such that the resist is completely exposed during pattern writing while the beam is in the "on" state. 3D pattern writing can be achieved by modulating the intensity of the beam to partially expose the resist. This type of exposure is commonly referred to as "grayscale" photolithography and is capable of creating microscale features with multilevel topography. In this work, a Heidelberg Instruments DWL 66 laser pattern generator was used to perform grayscale direct write exposures. This system uses an acousto-optic crystal to modulate the intensity of the beam to 31 different energy or "gray" levels where level 31 has the most intensity and level 1 is barely exposed. The resulting 3D structures in the resist can be transferred into Si or glass substrates using reactive ion etching. This project investigated two applications of this technology: micro-optics and microfluidics. Grayscale direct write lithography was used to successfully create arrays of microlenses in quartz and microfluidic filtering devices in Si.

Focused Ion Beam-Based Fabrication of Pt Nanoelectrodes

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In recent years, the electrical properties of materials with critical features less than or equal to 10 nm have become of increasing interest. Exploration of these properties often requires the fabrication of electrode pairs with a similarly sized interelectrode gap. Several techniques for fabricating these types of electrodes have been presented. However, most of these techniques are complicated and time consuming. Using a focused ion beam (FIB) workstation and a scanning electron microscope (SEM), we have established a reproducible procedure for rapidly creating electrodes with sub-10 nm interelectrode gaps. In this work, an FEI 611 FIB with a 25 keV Ga^+ beam was used to mill nominally 500 nm wide slits in Si_3N_4 membranes. The FIB was then used to deposit a line of Pt in the transverse direction of the slit using a chemically enhanced beam. As Pt is deposited, the slit begins to close in the region of the deposition. After characterizing this process it was possible to reproducibly arrest the deposition before the slit was closed yielding a nanometer sized interelectrode gap. SEM imaging of the fabricated structures showed interelectrode gaps produced by this process were consistently 10 ± 5 nm. Using a Keithley Instruments 236 source measurement unit, I-V testing revealed no significant leakage currents at biases up to 1 V verifying their electrical isolation.

Porous Carbons for Environmental Research

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Porous carbons are used primarily for purification purposes through adsorption of contaminants on the surface of the activated carbon. The specific functional groups on the activated carbon are important to know since different functional groups adsorb different chemicals. Because different functional groups have different pK_a values, a titration of the activated carbon indicates which functional groups are attached to the carbon. Also, a titration of two activated carbons with varying ionic strengths indicates the pH of zero charge for that activated carbon. This project's focus is to determine the appropriate equilibrium time for various activated carbons in titrations used for these purposes.

Properties and Performance of Molecular Glass Photoresists

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Molecular glasses are small molecules that have the ability to form amorphous films. They are promising candidates as low line-edge roughness resists because of their small size compared to conventional polymeric photoresists. This is especially important as the critical dimensions of photoresist features shrink ever smaller. The objectives of this project are to validate these materials as plasma etch resistant and to quantify the roughness of photoresist features. We ranseveral etch runs in order to find etch rates for various molecular glasses. Optimal exposure and development times were also found for these molecular glass resists. Profilometer measurements of resist film thickness were used in order to establish etch rates as well as post-development film thicknesses. Patterning on a 10x i-line stepper was also performed to produce patterns for observation via SEM.

A Study of Herringbone Graphite Nanofibers

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There is a lot of interest in the adsorption capabilities of Graphite Nanofibers because of their potential use for Hydrogen storage. Not only can this material store Hydrogen at room temperature, but can also desorb the gas relatively easily. In this we look into and characterize Herringbone Graphite Nanofibers in relation to their Hydrogen adsorption properties. Herringbone Graphite Nanofibers (GNF) was intercalated using a 1:1 mix of concentrated Sulphuric and Nitric Acid. This mixture was then exfoliated under a variety of thermal treatments. The resulting substance was studied using High Resolution TEM (HRTEM) and X-Ray Diffraction (XRD). Mass loss studies were used along with peak half width analysis to differentiate between structures. BET surface measurements and Pore Size Distributions PSD) were also utilized to characterize samples.

Patterning Proteins on Glass and Silicon Substrates

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In this research project, we examined conditions under which we can pattern multiple proteins for biosensor applications using a technique called micro contact printing. The technique requires casting a relief pattern in elastomeric PDMS (polydimethylsiloxane), coating it with molecules (BSA-Biotin and Rabbit IgG), and subsequently stamping the molecules onto the surface of a substrate. To create distinct patterns of BSA-Biotin and rabbit IgG, we used two stamps with differing geometric patterns. We utilized the produced patterns, by performing binding assays with quantum dot conjugates of streptavidin and goat anti-rabbit antibodies. Qualitative data analysis was performed by means of optical and fluorescence microscopy. The experiments showed that both proteins could be patterned and that both binding assays were successful when performed on separate substrates. When trying to create bi-arrays on a single substrate we found that the ability of the proteins to adhere to the surface was decreased and that non-specific binding during the assay was increased. Both factors need to be further examined to yield two distinct fluorescent images on a single substrate.

Catalytically Induced Microfluidics: Induced Fluid Flow as a Function of Anode Surface Area

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We previously reported on the channel-free autonomous movement of fluids and colloids through self-generated electric fields. The self-generated electric field is established by a catalytically induced reduction/oxidation reaction. Gold is the anode oxidizing hydrogen peroxide to oxygen and silver is the cathode, reducing hydrogen peroxide to oxygen. It is the migration of protons through the fluid and electrons through the solid (both from gold to silver) that establishes the electric field. The movement of the fluid is governed by electroosmosis and that of the colloid by electrophoresis. We reported that in general electrophoresis dominates over electroosmosis. Herein, we investigated the effect of the gold surface area on electroosmosis/electrophoresis by monitoring the movement of charged polymeric microspheres and 1-D conducting gold nanorods. We found that the speed of the charged polymeric spheres (silica and polystyrene) varied as a function of the gold surface area. Indeed, our initial findings show that the gold appears to be the rate determining step in the self-generated electric field.

Electron Beam Lithography to Improve the Performance of Organic Optoelectronics

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The project focused on the improvement in the performance of a standard organic solar cell using electron beam lithography. Roughening the bottom of an organic solar cell has been proven to increase its efficiency by preventing less excitons to recombine when light is incident on the cells, releasing more energy. Thus, we hope to achieve an increase in efficiency in a modified solar cell by making a device pattern on a silicon wafer with e-beam lithography, placing a PDMS layer to produce a "stamp" of this device pattern, and using the stamp in a "hot press" to emboss PEDOT on the underlayer of the cell. Efficiency of the un-embossed cells was verified using a computer interface and embossing PEDOT is underway. Other methods, such as adding the stamp as a cell substrate, were also considered in this project.

Silicon-Germanium Nanostructures

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The purpose of this project was to examine the effects of thermal annealing on film quality of Ge grown directly on Si, as measured by atomic force microscopy (AFM). The temperature stability of the Ge-on-Si films was observed for different annealing temperatures and times. AFM scans the sample surface to image the surface topography. These images can then be used to determine the surface roughness of the films, which indirectly provides an indication of film quality. For this experiment, thermal annealing conditions were applied to a set of eight wafers, each with a different Ge-on-Si growth condition. Each wafer was labeled and subdivided into 10 pieces. The first set of four wafers consisted of blanket Ge films grown over the entire Si wafer, with no additional layers. The second set had blanket Ge films, but with a thin high-k dielectric deposited on top. The 10 pieces of each wafer consisted of a control piece (with no thermal annealing), a piece used for film thickness measurement by AFM step height, 4 pieces that underwent rapid thermal annealing, and 4 pieces that were furnace annealed. All eighty pieces (8 wafers times 10 pieces each) were measured using the AFM system.

Limits of Adaptive Liquid Lens

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Practical limitations of a variable liquid lens using the electrowetting effect are investigated. Electrowetting, the change in contact angle at a solid-liquid interface as a result of an applied voltage, can be used to control the focal length of a liquid lens. SU8 chambers are prepared on a fused silica substrate with TiN electrodes, an Al mask layer, SiO2 dielectric layer and FOTS hydrophobic monolayer. Excitation of the resulting chambers causes variations in the observed far-field diffraction patterns thus verifying electrically-induced changes in refractive power. Such changes, for micron-sized lenses, could be used for spatial light modulators in adaptive optics.

Characterization of Nanoimprinting HSQ Material

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Nanoimprinting is technique for creating nanostructures based upon mechanical embossing. This process uses a mold with nanoscale surface relief structures to press into a polymer layer cast on a substrate. Under high pressures the polymer will be shaped by the mold. We will be looking at the rheological behavior, which determines how the polymer will deform under varying pressures and temperatures. We will look specifically at HSQ and find how it will behave in the imprinting process. Determining whether this polymer has a Newtonian (or viscosity independent of shear stress), or non-Newtonian flow will allow us to better understand the nanoimprinting process. Understanding how time and pressure affect the depth of an imprint will make it possible to precisely engineer devices using this method.

Fabrication of Metallic Microparticles for Use in Drug Delivery Studies

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Novel drug carrying particles are essential in establishing the most efficient delivery possible. Most current particles are polymeric in nature, but metallic particles could have major advantages over polymeric carriers. This project focused on the fabrication of metallic microparticles for use in biomedical research, specifically for research in treating cancer. To produce the particles, photolithographic and electron-beam evaporation processes were used to pattern silicon wafers and deposit metal onto them, respectively. The wafers were coated with a phosphosilicate glass (PSG) layer, which was subsequently covered with low-stress silicon nitride (SiN). The nitride layer was patterned and coated with layers of chrome and gold which were then lifted resulting in four different shapes: a filled circle, a circular ring, a solid rectangle and a rectangular ring. After patterning, the PSG was etched, releasing the metallic particles on nitride bases. These particles were then examined using an Atomic Force Microscope (AFM) to characterize their mechanical properties.

Colloidal Dimers for Reduced Symmetry Photonic Crystals

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Photonic crystals are dielectric structures made with a periodic variation of refractive index. These lattices allow the possibility for the manipulation of light in the same manner that semiconductors control electrons. This may lead to applications in zero-threshold lasers, optical switches, coherent LED emission and low loss wave guiding for all optical circuits. The primary concentration of the project was to synthesize monodispersed, non-spherical, high refractive index colloids with a well-defined, asymmetric shape to be used as building blocks for photonic crystal structures with stable three-dimensional band gaps. To achieve this aim, crosslinked polystyrene seed particles with varying levels of divinylbenzene (DVB) were synthesized. A seeded dispersion polymerization technique was utilized to swell the seed particles and create polystyrene dimers. Samples containing the asymmetric particles along with other morphology types were synthesized. Future work towards creating pure dimer samples is planned. Parallel to the dimer synthesis portion of the project, we have been working to coat the polystyrene seed particles with materials of high refractive index. Polystyrene seed particles were successfully coated with zinc sulfide and titania. These core-shell particles have been used to create hollow high refractive index shell structures by etching the polystyrene core with toluene.

Structural and Physical Characterization of Supramolecular Diblock Copolymers

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Recent interest in diblock copolymers has grown because of their ability to form periodic structures on the size scale of 10-100nm; hence, these materials can be used for advanced lithographic templating applications. However, supramolecular diblock copolymers, in which the bond between the two blocks can be reversibly broken at high temperature, have not yet been effectively characterized. In order to better understand their behavior, we are developing a model covalent diblock copolymer system. The microphase separation of four symmetric poly(benzyl methacrylate-block-tert butylacrylate) diblock copolymers with different molecular weights ranging from 10000 to 28000 g/mol was compared through several techniques. We were especially interested in measuring their order-disorder transition temperatures (T_{ODT}) by using small-angle X-ray scattering and rheology. The degree of polymerization (N), volume composition, and chemical structure were the three major variables that could affect the diblock copolymers' ODT. By studying the ODT of the symmetric diblock copolymers, the relationship between temperature and N can be determined, providing a reference point for future studies of more complex systems.

The Relationship of Line Edge Roughness and Contrast by Deep UV Immersion Interferometric Lithography

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In today's microchip industry, focus has been shifted to immersion lithography due to water's 44% higher refractive index than air for deep UV which allows for lens NA values greater than 1. This new technology has been allowing for the printing of smaller and smaller structures on silicon wafers. However, the problem of the roughness of these features is gaining importance at such small sizes. This experiment attempts to ascertain the relationship between the severity of line edge roughness (LER) and the reduction of contrast. To accomplish this task, 150mm silicon wafers are coated with a dual layer of ARC and an 80nm layer of IRC1500 positive photoresist. These wafers, behind a film of de-ionized water, are exposed to varying amounts of two-beam interferometric light and one beam light generated by a 193nm Excimer Laser (this variance produces differing contrast), which produce a 71nm half-pitch. The exposed areas are cleaved from the wafers, gold plated to ~40Å, and viewed under a scanning electron microscope at 100kX and 150kX. The pictures taken from the SEM undergo a Fourier Transform which is analyzed to produce a value for the LER which can be plotted against the percent contrast used in the sample.

Contactless DNA Spotting on Biosensors

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Small, finely spaced magnetoresistive biosensors need to be individually functionalized with various DNA probes. Due to the small pitch of different funtionalization spots, the functionalization chemistry is best applied to the biosensors with a precise robotic applicator. We currently have a robotic system that will perform DNA spotting with a hard needle. The present problem is that contact is needed to deposit the DNA onto the targeted sensor. The physical contact damages the sensor's surface which degrades its functionality. By developing a contactless approach, damage to the sensor will be avoided. Entirely contactless deposition of a DNA-containing fluid droplet is more difficult to achieve with a high degree of accuracy than hard-contact printing. We will therefore try to implement a soft needle or inkjet printing approach that will avoid physical contact, and give us the precise and smaller spotting sizes that only hard-contact printing could so far provide. We will be using a scanning electron microscope and/or tapping mode atomic force microscope to assess spot sizes, spotting uniformity, and the reduction of any damage to the sensor. If successful, the spotting technique will probably be carried over to a larger-scale production, allowing for cheaper and more standardized biochips.

Bi-Layer Lithography Using Nanoimprinting

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Nanoimprinting is a way to replicate nanoscale features of 10nm or less in size on one surface into another. To reproduce nanoscale features, traditional techniques such as electron beam lithography can cost thousands of dollars per wafer and can be time consuming. With nanoimprinting, only a master using traditional fabrication techniques needs to be made and it can be stamped repeatedly into polymer coated substrates. These patterns can then be transferred to the substrates by reactive ion etching techniques. Chlorine-based reactive ion etching is often used to etch nano-scale feature dimensions deeply into both silicon and many compound semiconductor materials, such as GaAs and GaN. Since chlorine-based reactive ion etching often attacks polymer at similar or higher rates than the substrates, an intermediate hard mask, such as SiO_2, is desired to provide a better etch mask for the substrate. In this work, the bi-layer process of imprinting into a polymer and transferring the pattern into SiO_2, by fluorine-based reactive ion etching, is developed and described.

Ferroelectric Nonvolatile Memory Materials - Fundamentals of Reliable Ferroelectric Switching.

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Fatigue of ferroelectric films is a major difficulty in the advancement of these materials in Ferroelectric Random Access Memory (FeRAM / FRAM) nonvolatile memories. Little is known in what causes polarization fatigue in thin ferroelectric films. It has been suggested that fatigue is related to trapping of carriers injected into Pb(Zr,Ti)O3 (PZT)films from the PZT/electrode interface. Optical methods have been suggested to excite these traps with single wavelength energies and ultimately describe the trap concentration and energy of the traps using current-voltage measurements. This can be accomplished by creating a thin top electrode such that the electrode does not absorb most of the injected photons, yet still does not affect the electrical characteristics. In this study, various electrode configurations, electrode thicknesses and different electrode materials will be examined. It is this work's goal to provide process parameters and guidelines for depositing a thin, transparent and high quality top electrode in order to understand and quantify trap concentrations in ferroelectric films.

Characterization of Beam Aberrations due to Axial Magnetic Field Tilt in DIVA for Massively Parallel Electron Beam Lithography and Inspection

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Theoretically, electron beam systems can achieve sub-nanometer resolution, limited only by diffraction and spherical aberration. However, to achieve high throughput for lithography and inspection, large currents are needed. In single beam systems, the requisite current densities limit resolution because of space charge effects. Multibeam systems circumvent this limitation by distributing current over many separate beams writing simultaneously. DIVA (Distributed axis Variable beam shaping), proposed by Groves et al., takes advantage of the properties of the simplest electron lens, a uniform axial magnetic field, to focus an array of beamlets. Advantages of this configuration include extreme simplicity of the optics, scalability, and low aberrations. Previous work with uniform field systems has successfully demonstrated unity magnification SEM operation for a single beamlet, with resolution determined only by the size of the beam-limiting aperture. Before constructing the multibeam system, we will determine beam aberrations due to tilt angle with respect to the uniform axial magnetic field both experimentally and theoretically, and specify the degree to which field alignment is critical in the proposed system.

In Situ Wet Oxidation of AlGaAs for Fabrication of Vertical-Cavity Surface-Emitting Lasers

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Recent research has uncovered a wide variety of uses for vertical-cavity surface-emitting lasers (VCSEL); including such applications as brain wave sensing and ultra-high density optical data storage. One especially delicate component of a VCSEL is the oxide aperture. This structure serves several purposes, including restricting electron flow through the device - which keeps electrons in the active region longer - and reducing photon scattering at the tip of the laser cavity, which improves efficiency. In our project the aperture is a thin layer of $Al_{0.98}Ga_{0.02}As$. It is oxidized laterally from the outside in to form a ring. In the past this oxidation process has been performed in a conventional furnace, but the results can be difficult to predict, and the size of the oxide aperture must be very precise. The goal of this project is to configure an existing furnace designed for *in situ* oxidation monitoring to produce consistent and even oxidation on arrays of VCSELs. Once the system is configured, a repeatable procedure will be produced for using the furnace for oxidation. Then the system will be used to fabricate VCSELs that will be part of a new ultra-high density optical storage device.

Nanomechanical Structures for Digital Logic and Analog Amplification

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As electromechanical systems decrease in size, researchers have become interested in scalability effects. We address these scalability issues with regards to nano-scale electromechanical systems (NEMS) cantilevers and present potential new applications. The primary issues are physical size, pull-down voltage, switching speed, and Brownian motion noise. The fabrication process dictates the physical size limit, and modeling shows that the pull-down voltage can be held constant by appropriately scaling relevant variables. The spring constant is the primary factor controlling both switching speed and Brownian motion noise, and is inversely proportional to the pull-down voltage. The modeling leads us to design an acceptable compromise. After starting fabrication, we discover that fabrication-induced stress causes the cantilevers to curl upwards after release. We are devising schemes to circumvent this. Small cantilevers can reduce drain-source leakage currents in complementary metal-oxide semiconductor (CMOS) transistors, which benefits low-standby power transistor applications. We design the NEMS cantilevers to sit atop CMOS transistors and unlatch the power connection when the transistor is off, following the International Technology Roadmap of Semiconductors. Modeling indicates that this design is able to exceed specifications in the key area of interest, power leakage. The cantilevers can also be used as logic gates and SRAM devices.

Fabrication of Two-Dimensional Arrays of Inorganic-Binding Polypeptides for the Template-Directed Self-Assembly of Nanoparticles

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Due to the unique optical, electrical, magnetic, and catalytic properties exhibited by nanoparticles, there has been a surge of interest in nanotechnology for developing techniques to organize nanoparticles on various surfaces in a spatially resolved manner. It has been found that by combining inorganic nanoparticles with biological molecules a high degree of organization and binding specificity can be acquired. A septapeptide which binds to platinum was modified to form three repeat and one repeat, constrained genetically engineered polypeptides for inorganics (GEPIs). This study focuses on chemical and physical methods of patterning the GEPIs. In the chemical patterning method, the GEPIs bind to a self-assembled monolayer of (4-mercaptophenyl)-anthrylacetylene (MPAA). A high degree of binding specificity is possible due to Schiff base linkages, when the MPAA's aldehyde reacts with amine groups in certain amino acid residues to form a C=N bond. With physical patterning, specific binding is possible only for the GEPI constrained with an amino acid containing a disulfide bond, because the two sulfurs are able to absorb onto the Au surface. The protein coverage in a two-dimensionally confined area was characterized using atomic force microscopy. The spatial conformation and packing of the immobilized proteins were compared for the two methods.

Compositional Analysis of W and Ti Bilayer Electrodes at the Metal-Dielectric Interface and Its Effects on Work Function

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As nanoscale transistors decrease in size, a new material is needed to replace the polycrystalline silicon gates currently used in these metal oxide semiconductor (MOS) devices. Metals are being investigated as the proposed replacement gate material because they would eliminate the problems of dopant penetration and poly-depletion currently seen in poly-Si gates. In this project, we look at the relationship between W and Ti metal layer concentrations in a bilayer gate electrode and the device's resulting work function. Specifically we investigate interactions at the metal-dielectric interface and determine how altering the thickness of a thin metal layer affects the work function. Materials characterization includes X-ray diffraction (XRD) and X-ray photoelectron spectroscopy (XPS), and correlations will be made to the work function as determined by capacitance-voltage measurements. A fundamental understanding of material science at the nanoscale is imperative in providing us with the ability to apply the knowledge to work function tuning, in creating the next generation of MOS devices.

Electronic and Thermoelectric Properties of Semiconductor Nanostructures

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The incorporation of low dimensional structures into materials often yields appreciably altered properties than found in typical bulk or thin film materials. For this reason, nanostructures are used to tailor semiconductor characteristics for enhanced performance. In this project, we explore the integration of aligned InAs quantum dots into GaAs for improved thermoelectric merit, and the addition of nitrogen clusters into dilute semiconductor heterostructures for a variety of applications (or for use as high electron mobility structures). We will focus on the development of these two novel materials, as well as the design and implementation of test structures to facilitate measurements.

DNA Pyrosequencing Using Electrowetting Droplet Transport Chips

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Pyrosequencing is a new method of DNA sequencing which shows promise of being able to cut costs by several orders of magnitude while increasing the throughput. Electrowetting techniques will be used to miniaturize pyrosequencing by utilizing electric fields to control the movement of nano-liter sized droplets. The DNA will be attached to superparamagnetic beads while the fluids required for pyrosequencing will flow over the beads. In this project, a bead trap will be designed and tested in order to prevent the loss of DNA during the sequencing process. Microscopy will determine the success of the bead trip. An effective bead trap is crucial if pyrosequencing is to replace current DNA sequencing methods.

Social and Ethical Dimensions of Nanofabrication

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This project focuses on the social and ethical dimensions of nano research and development. During my internship at Cornell's NanoScale Facility I conducted ethnographic work and interviews with a diverse group of researchers at CNF ranging from undergraduate students, to staff members and industry users and produced a video that reflects some of the themes that emerged from these conversations and investigations. Research participants discussed the social dimensions of making science by interacting with others and sharing the lab with them, how is safety an overriding concern, research's toll on the environment, and expressed their opinions on public communication and how it relates to hype and funding. Looking at all these factors, some were then able to speak about the future and the difficulties of navigating the world of Nano. Put together these findings allude to the centrality of social and ethical issues, often considered extra-scientific, in the practices of nano-researchers. The resulting video is just the beginning of the studies to come on the social and ethical dimensions of Nanofabrication.

Growth of Cubic Silicon Carbide on Silicon Nano-mesas

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Silicon carbide is one of the hardest materials known, and as such can be taken advantage of to make highly sensitive piezoresistive sensors. However, wafers of silicon carbide are not cheap, and generally come in smaller diameters, whereas silicon is ubiquitous and inexpensive. Silicon pillars and tips were fabricated with 2, 3, 4, and 5 µm spacings. The bases were 1 µm with the pillars having an aspect ratio of 10:1 and the tips 1:1 . A growth mask was applied to the tips only, and CVD was used to grow SiC on the structures. 4, 6, 8, 12, 15, 30, and 60 minute growths were performed and characterized. So far, the 2 µm spaced tips and pillars have exhibited the best terrain on which silicon carbide can grow, as the film seems to have coalesced to a further degree than on other spacings. The high aspect ration of the pillars and small nucleation area of the tips are expected to relieve strain due to the large lattice mismatch (20%). Characterization is done using SEM and XRD to see the growth and determine the crystal structure.

Preparation of Silver Nanoparticle Formulations For Biocidal Applications

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The preparation of silver nanoparticles by reduction in aqueous media is investigated using ascorbic acid, citric acid and propylene glycol as reducing-complexing agents. The effects of pH, temperature and concentration of reagents are detailed. Sufficiently stable media are characterized by UV-visible spectrophotometry and light scattering spectrometry. Silver nanoparticles have possible biocidal applications that would aid in purifying drinking water and selected food products.

Electrical and Structural Characterization of GaN for Optoelectronic Applications

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Many possible applications for Gallium Nitride (GaN) are currently being researched in the field of optoelectronics. GaN has a wide, direct bandgap, which is useful for making LEDs that emit light in both the visible and ultraviolet spectrums. This project focuses on the growth of N-face GaN films, specifically InGaN/GaN and p-type films. X-ray diffraction (XRD) is used to analyze the crystallographic structure and composition of GaN films. XRD analysis of InGaN/GaN multiple quantum well structures shows that at a given growth temperature, more Indium is incorporated into N-face films than into Ga-face films. Additionally, p-type GaN:Mg films were grown and analyzed using Hall effect measurements. Practical uses of N-face GaN derive from the fact that it has the opposite polarization from Ga-face GaN with respect to the growth axis. It is thus useful for polarization engineering in optoelectronic devices.

Effect of SiO2 Shell Coating on High-Temperature Annealing of FePt Nanoparticles

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Iron-platinum nanoparticles are a topic of increasing scientific interest due to their potential applications in the fields of high-density data storage. In order for the particles to obtain desired magnetic properties, however, they must be annealed at high temperatures, which commonly results in sintering and loss of particle order. The presentation details the results of a study employing the use of SiO2 coated FePt nanoparticles in an attempt to acheive sinter-free annealing conditions.

Hexabenzocoronene (HBC) as a 1-D Organic Semiconductor in FETs

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Organic field effect transistors (FETs) have potential applications in low voltage, low cost, and mechanically flexible devices, including displays. However, organic FETs face problems of low mobility and high degradation relative to conventional inorganic FETs. Hexabenzocoronene (HBC) derivatives are organic semiconducting materials due to their strong π-π interactions and may self-assemble into 1-dimensional nanostructures in their liquid crystalline phase. In this work, we studied the molecular packing of an HBC derivative, tetradodecyloxyhexabenzacoronene (THBC), by atomic force microscopy (AFM). In spin-cast films at room temperature, the molecules do not form perfect 1-D columns but are slipped, due to strong π-electron repulsion between large aromatic cores. To align the THBC molecules, a thin layer of PTFE (Teflon) fibers was deposited on Si/SiO2 using a friction transfer method, forming grooves that may have guided the self-assembly of THBC. The performance of FETs fabricated from films with and without the alignment was then compared.

Growth and characterization of vertically aligned high-density GaN nanowires by reaction of Ga with NH_3 with Ni catalyst

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Previous work has been documented on the growth of vertically aligned arrays of gallium nitride (GaN) nanowires by a reaction of Ga and ammonia (NH_3) using gold (Au) as a catalyst. Such products are important in the fabrication of optoelectronic nanodevices. In this work, synthesis of single crystal GaN nanowires and arrays of vertically aligned nanowires was achieved through a catalyst assisted vapor-liquid-solid process by the reaction of Ga and NH_3 in the presence of a nickel (Ni) catalyst. The experiments were carried out inside a tube furnace at a temperature of 1000°C and pressure of 5 Torr with anhydrous ammonia flow rate at 20 sccm. Metal Ga and Ni patterned substrates were placed on separated boron nitride (BN) boats in a quartz liner inside the furnace. The optimal growth parameters were determined on Si substrates which generated a high density of nanowires with diameters between 30 and 70 nm, several micrometers in length, and grown in random directions. MgO (111) and a-plane Al_2O_3 sapphire substrates were then used for controlled growth orientation which produced vertically aligned GaN nanowires on areas where the catalyst was present. Our results offer a simpler alternative to synthesize GaN nanowires using a much less expensive catalyst metal from the currently used Au-catalyst process.

Molecular Packing of Charged Conjugated Polymer Studied by Atomic Force Microscopy

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Conjugated polymers are polyunsaturated compounds which consist of at least one backbone chain of alternating double-and single bonds. These organic semiconductors are used in various applications such as light-emitting diodes, photovoltaic devices, field-effect transistors, and flexible displays. Emission color (band gap) can be tuned by molecular structures. The conformation of polymer chains and the subsequent packing of these chains in film influence the electronic properties. By introducing charged side-groups, the polymers are soluble in water or methanol, therefore, can find application in biosensors. Also, the polymer conformation can be controlled by changing solution pH or adding salt. We studied two charged conjugated polymers (conjugated polyelectrolytes), trimethylammonium polyfluorenes, that contain either electron transporting unit (ETP) or hole transporting unit (HTP) under different processing conditions. The HTP contains a 1,4-phenylene unit whereas the ETP has a 2,1,3-benzothiadiazole unit. Specifically, we examine how changing the polymer concentration, solvent (water versus methanol), and salt (type of salt, NaBIm4 or NaBr, and salt concentration). Change in polymer conformation in solution and molecular packing in film are monitored by spectroscopy and atomic force microscopy (AFM).

Engineered Protein Scaffolds for Interaction with Nanoparticles

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The focus of this project is to exploit the self-assembly properties of proteins to arrange inorganic compounds in predictable patterns. Part of this effort has involved the genetic and biochemical manipulation of the *E. coli* TraI protein, a DNA helicase involved in F plasmid conjugation. TraI has a high affinity for DNA, and we are using TraI-derivatives with specific metal binding capacities to make DNA-protein-nanoparticle assemblies. Polypeptide sequences that mediate binding to gold were incorporated into previously identified TraI-permissive sites, without altering the in vivo function of the TraI protein. Two of these TraI proteins, TraI-GBP7Q and TraI-GBP5Q, have been purified and subsequently imaged using an atomic force microscope. The proteins have been observed binding to both single-stranded DNA and gold nanoparticles, thus producing a linear ordered array of nanoAu. These conjugates of DNA-TraI-nanoAu which demonstrate a binding and ordering of gold nanoparticles along a DNA strand can then be deposited on a flat substrate as a proof-of-concept for making devices.

Computational Studies of Quantum Dot Formation and Morphological Evolution

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Quantums dots are nanoscale structures that form during heteroepitaxy of a thin film onto a substrate. These dots form as a result of the lattice misfit (the difference between the lattice parameters of the film and the substrate materials), resulting in strain. Quantum dots exhibit distinctive properties, such as electrical properties, that have proven useful for recent advances in nanotechnology, resulting for example in quantum dot lasers, and could enable further advancements in electronics and computing. The purpose of the project is to build a mathematical framework for describing the anisotropic surface energies to be implemented in the simulations of growth of quantum dots and other relevant materials. In the first part of the project, the commercial program, Mathematica, was used to find mathematical descriptions of anisotropic surface energies with various symmetries that are expected from the underlying crystallographic structure of materials. Two-dimensional descriptions of the surface energies were created first, which were then extended to three-dimensional descriptions. After the mathematical formulas of the descriptions were obtained, the equilibrium shapes, or Wulff shapes, associated with these surface energies were obtained, again using Mathematica.

Electromechanical Coupling of One-dimensional Dolids

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Materials exhibit unique electrical and mechanical properties at the nanoscale such as quantized conductance and high elastic modulus which make them ideal for the next-generation sensors and electronics. A device capable of measuring forces with pico-Newton resolution and displacement with nanometer resolution, in an optical microscope, has been fabricated. The design philosophy for the sensor exploits the amplification of displacement and attenuation of structural stiffness in the post-buckling deformation of slender columns. The research experience aims to (a) explore reliable methods for placing the nanowire or nanotube on the device or co-fabrication and (b) measure the strain-conductance coupling of ZnO nanowires. The devices have been patterned on silicon-on-insulator (SOI) wafers using UV photolithography and DRIE. The movable silicon beams were made freestanding using vapor-phase HF. Dispersion for ZnO nanowires has been characterized and a Focused Ion Beam with a nanomanipulator probe was used to place the nanowires on the device. An upper bound of 5 GPa for the Young's modulus of ZnO nanowires has been observed. Stress-strain curves for these nanowires have been computed, and electromechanical characterization experiments are being conducted to determine strain-conductance coupling.

Adhesion of Thin-Films used in Nanoimprint Lithography and Embossing

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Embossing and nanoimprint lithography (NIL) are promising new ways to create micro- and nano- scale features, respectively. Both processes involve pressing a mold or stamp into a polymer film, curing the film while the two are in contact, and then removing the mold. One of the critical issues during NIL and the embossing process is removing the mold/stamp from the polymer film because they tend to adhere to one another. This may eventually result in damage or defects in the mold which will defeat the purpose of these techniques. The goal of this project is to characterize the adhesion of the salient polymer-mold interfaces. Model polyacrylates were cured on silica surfaces with and without a fluorine based release layer and were separated using a common fracture mechanics technique to examine the effects of interface chemistry on adhesion. The release layer did not significantly reduce adhesion but ensured that the fracture path remained at the polymer – silica interface. The effects of mold pattern geometry on adhesion energies were also examined. It will be demonstrated that increasing aspect ratios of lithographically patterned arrays of silicon structures coated with Teflon yield higher fracture energies.

Universal File Format for First Principles Codes

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Currently, over twenty density functional (DFT) codes exist for calculating properties of crystal structures and molecules using first principle approaches. While each has its own strengths and weaknesses when describing a particular system, the ability to migrate from one approach to another easily is essential for comprehensive research. In this work, we create a program that can convert between multiple formats of DFT codes. As a test case, we examine a magnetic nanowire system, converting between two popular DFT codes, LMTO and Abinit. LMTO uses a compact basis set derived from atomic-like orbitals to calculate system properties quickly. While LMTO is very efficient for closed pack systems, special care is required for structures with large amounts of open space. Abinit, by contrast, is based on a plane wave basis and can handle a wide range of systems at the expense of greater computation time. Since the plane wave basis set is not localized, Abinit treats empty space more effectively than LMTO The system properties calculated using both techniques are compared and situations where format conversion would be ideal are also discussed.

Characterization of Thick Photoresist

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Single layer 10µm - 100µm thick photoresist is useful for a number of applications including bump-plating lithography and wafer level packaging (WLP). In this project a negative photoresist (BPR-100 manufactured by Rohm & Hass) was characterized. Various parameters were investigated including spin speeds, exposure time, UV-light wavelength, and development time. Absorbance data indicated that this photoresist was most sensitive at wavelengths of 260nm - 310nm but was also sensitive at 350nm - 400nm. Exposure was done using a Karl Suss UV mask aligner (power density of 8.1mW/cm^2 at 405nm) and a PSD-UV exposure system (power density of 0.66mW/cm^2 at 240nm). By varying the spin speed from 600 rpm to 6000 rpm the resist thickness varied from over a 100µm to 12µm. Optimum exposure time varied with resist thickness. Resist side walls were nearly vertical. Liftoff of 3µm of aluminum metal was successfully accomplished using BPR-100.

Integrated UHF Magnetic Transducers

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Creating a surface acoustic wave (SAW) device on a silicon substrate would allow for integration leading to a more well defined device. Instead of using piezoelectric materials, our device creates SAWs using magnetostriction. A copper wire is embedded in a magnetostrictive material, $Co_{46}Fe_{46}Ta_3Zr_5$. Current passed through the wire creates a circumferential magnetic field around the wire. The magnetic moment of the $Co_{46}Fe_{46}Ta_3Zr_5$ rotates in the presence of the magnetic field, elongating the material along the direction of the field. As alternating current passes through the wire, the elongation and relaxation of the magnetic material creates compression waves in the silica substrate. We detect these SAWs on the silica substrate using another SAW device. Regularly spaced wires simultaneously creating SAWs help reinforce the SAW. I have fabricated two designs for the device. One design includes magnetic material only above and below the copper layer. The insertion loss for this design has been approximately 70 dB. The second design has magnetic material on the sides of the wire as well as the top and bottom in order to improve magnetic response and the insertion loss. We are currently in the process of overcoming challenges associated with characterizing the devices at ultra high frequencies.

Gold Deformation and Characterization in Microelectromechanical System (MEMS) Switch

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As a soft metal, gold undergoes significant deformation at the contact points in a MEMS switch causing failure after repeated cycles. An adhesion force is created as the indentation into the gold increases causing the switch to stick in the closed position. Additionally, the gold curiously retains some grain roughness even after repeated cycles of indentation. By replicating the roughness of the gold at a larger scale with the placement of gold squares on a substrate and nanoindenting, a better understanding of the deformation is obtained. Greater insight into the mechanics and behavior of the nanoscale gold deformation is achieved through varying the cycles, force, gold feature substrate, and the feature aspect ratio of the nanoindentation

Microfabrication of a Parallel-Array DNA Sequencing Chip

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DNA sequencing is essential to the field of genomic research and it is essential that it be performed as efficiently as possible. Pyrosequencing is a relatively new innovation that confirms a correct nucleotide addition by emitting light through cascading enzymatic reactions. This method is a promising alternative to the commonly used Sanger sequencing, because it can potentially be miniaturized for far less cost. The objective of this work is to create a parallel-array pyrosequencer on a chip. The current obstacle is to bring a light detecting camera sufficiently close to the microwells where the sequencing reactions take place so it can capture the emitted light and eliminate cross talk between adjacent wells. We plan to accomplish this by bonding a very thin nitride membrane on top of the reaction microwells on which the camera can sit. This will bring the camera to within microns of the reaction wells and enable efficient light capture. If this procedure succeeds, we will have developed an enabling technology for a scaled down DNA sequencer.

Electrical Characterization of Semipolar Gallium Nitride Thin Films

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Considerable economic and environmental savings will be achieved through the successful development of high efficiency solid state lighting sources. Considerable breakthroughs have been made in the development of GaN based blue, green, and white light emitting diodes (LEDs) and blue laser diodes (LDs). Typically, GaN optoelectronic devices are heteroepitaxially grown on C-axis oriented sapphire substrates using techniques such as metalorganic chemical vapor deposition (MOCVD). Such structures suffer from polarization-induced internal electric fields along the (0001) growth direction which limit the radiative efficiency of the device. Recent theory suggests that growth of a semi-polar GaN orientation will reduce these internal fields and an improvement in device performance. However, the successful growth methods for semi-polar GaN thin films are still under development. GaN crystals grown under different conditions call for multiple characterization techniques such as measuring the Hall Effect using the Van de Pauw technique, a method of measuring the resistivity and Hall coefficient on lamellae of arbitrary shape. It is from these properties that the mobility and concentration of charge carriers are derived. The two variables allow for the comparison of the quality of different crystals, leading to the successful optimization of growth conditions for semi-polar GaN semiconducting thin films.

Gallium Nitride Nanowire Growth and FET Device and Bio-sensor Fabrication

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GaN nanowires (NWs) are one of the promising nanoscale materials because of their chemical inertness, optical properties, and wide band gap. Because of these properties GaN NWs may be used to fabricate devices such as field effect transistors (FETs) and bio-/chemical sensors. This study focused on controlling the growth of the NWs for fabrication of FETs. GaN NWs were grown using annealed Ni as catalyst. To control NW growth density, the anneal time was varied from 1-6 minutes, and the temperature was varied from 850˚C to 1050˚C. The initial thickness of the Ni and the NW growth conditions were varied as well. Using standard lithography processes, several Ni patterns were created and NWs were grown from the patterns. Patterning the Ni allows for further control over the density of the NW growth. FETs have been created by putting a source and drain over the NWs. These transistors will be used to measure the DC current-voltage characteristics of the GaN NWs and may have future bio-sensor applications.

Surface Preparation for 3C-SiC Growth on 3C- and 6H-SiC by In-Situ Etching in HCl

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Thin active layers of silicon carbide, a highly desirable electronics material, can only be deposited on a substrate by growing an epitaxial layer. The epitaxial layer is subject to crystallographic defects such as stacking faults and double-positioning boundaries. Past research has shown that the surface quality of the substrate is critical to good epitaxial growth with few defects. An effective etching process can remove oxides and improve the surface morphology. The goal of this project is to optimize an etching process that will create a smooth surface on a 6H-SiC substrate for growth of a low-defect epitaxial layer of 3C-SiC. By developing a process that takes place within the chemical vapor deposition (CVD) reactor before epitaxial growth, we will preserve the benefits of the etching process. The *in situ* etchants used in this project are H_2, which will remove the native oxide, and HCl, which will etch the SiC. Holding the pressure and H_2 flow constant, we varied the time, temperature, and amount of HCl flow to find an etch rate for the 6H-SiC. After finding effective etching parameters, we grew and characterized an epitaxial layer of SiC.

Nanometer-Thick Dielectric Films Deposited by Electron Cyclotron Resonance (ECR) Plasma-Enhanced CVD System

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Depositing ultra-thin high quality dielectric films to be compatible with nanoscale devices is a challenge. The purposes of this study are: (i) to investigate the deposition of nanometer thick silicon nitride films using ECR-PECVD; and (ii) to characterize these films. Nitride films about 50 nm thick were deposited at different silane flow rates. X-ray photoelectron spectroscopy (XPS) and spectroscopic ellipsometry were used to analyze the compositions and determine the thicknesses of these films. The results showed a strong relationship between the index of refraction and the composition of the films. To determine a similar process-property relationship in films thinner than 10 nanometers, we had to account for property changes in such ultra - thin films, as well as overcome the instrumental limitations of the ellipsometer. A mathematical formula that uses XPS peak intensity ratios to estimate the thickness of ultra – thin films is applied via a MATLAB program written for this purpose. The preliminary results showed promising evidence that the thickness of these silicon nitride films can be estimated using XPS peak intensity ratios, with greater accuracy than current ellipsometry techniques.

Nanoscale Surface Acoustic Wave Sensors for Early Cancer Detection

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The variety of research areas involving applications of surface acoustic wave (SAW) devices has recently been extended to include the field of biosensor technology. The velocity of the surface acoustic waves, and thus the operating frequency, is dependent upon the mass density of the device. A biolayer containing antibodies directed against cancer cell proteins is added to the SAW device. If these proteins are present in the environment so that binding to the antibodies occurs, a change in mass of the device and a subsequent change in operating frequency results. This change can then be detected by interrogating the device with a radio frequency (RF) signal, which is reflected back via an input/output interdigital transducer so that the signal can then be analyzed for perturbations caused by binding effects within the biolayer. Presently, the SAW device understructure has been fabricated using e-beam lithography and tested for response to electrical probing. Ultimate goals include addition and testing of the biolayer and antenna for RF interrogation.

Focused Ion Beam (FIB) Patterning And Investigation of CoCrPt-oxide Perpendicular Magnetic Recording Media

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Patterning perpendicular magnetic recording media is one of the methods being investigated currently in order to increase magnetic storage capacity, and allow the next generation of recording devices to attain storage densities above 300 Gb/in^2. Work has been done with patterning CoCrPt perpendicular media, but so far there has been no work done patterning CoCrPt-oxide media. This type of film is considered to be a strong candidate for perpendicular recording media due to its magnetically decoupled grain structure. In this project we examine a variety of patterned magnetic bits with decreasing size, reaching approximately 100nm, created by patterning conventional CoCrPt-Oxide thin-film perpendicular recording media using focused ion beam (FIB) milling. FIB-patterned structures are characterized using scanning electron microscopy (SEM) and atomic force microscopy (AFM). Using magnetic force microscopy (MFM) we determine the magnetic characteristics of the patterned bits. These results give us insight into how useful it will be to pattern CoCrPt-oxide perpendicular magnetic films for use in the next generation of hard disks.

Nanofiber Catalyst Production using Anaerobic Bacteria

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The goal of this research is to carry out comparative studies on nanowires fabricated using nanoparticle (NP) catalysts from several different strains of bacteria. The research included identifying candidate bacteria in the literature, obtaining those from researchers, and carrying out initial bacterial culture studies. All the NP-producing bacteria turned out to be anaerobic with complex bacterial culture requirements: magnetotactic bacteria strains MS-1, MV-1, and MC-1, which produce magnetite (Fe_3O_4) NPs; and a strain of sulfate-reducing bacteria (SRB), *Desulfovibrio gigas*, which may produce ZnS NPs. The Fe_3O_4 NPs are well-characterized crystals and relatively large (>40 nm). ZnS NPs are much smaller (~3 nm). The size and shape of these catalysts affect the diameter and cross section of the nanowires, which are important in potential nanoelectronic applications. A test was planned for use of zinc oxide nanowires in a nano-biosensor for detection of molecules tagged with green fluorescent protein (GFP). Since formation of ZnS NPs has only been documented for mixed natural cultures of SRB, an initial study examined media that might stimulate ZnS NP growth in *D. gigas*. Scanning electron microscopy (SEM) and energy dispersive spectrometry (EDS) will be used to detect the presence of ZnS particles.

Whispering-Gallery-Mode Microdisk Optical Biosensor: Fabrication and Characterization

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The need of sensitive yet miniaturized instruments for bio-detecting has accelerated the development of micrometer-scale optical biosensors. Microsphere biosensors based on the resonant shifting of whispering-gallery mode (WGM) has been demonstrated previously. Despite its high sensitivity (high Q-factor), microsphere faces challenges such as large mode volume, size is uncontrollable during fabrication, and hard to be integrated with other optical components. In this work, the fabrication of microdisk WGM resonators using photolithography and wet etching is studied. SiO2 microdisks with diameters ranged from 400 to 1200 μm and thicknesses of 1 and 15 μm were fabricated on Si substrates. Preliminary spectroscopic test showed that the as-fabricated disks have a Q-factor better than 10^4, indicating that microdisks are viable alternatives to microsphere sensors. Since the fabrication process used in the study is compatible with that in standard microfabrication, the sensors can be easily integrated with other electronic and optical components on a semiconductor chip. Further improvement in sensor fabrication and performance is also investigated.

Synaptic Ultrastructural Reconstruction Using Serial Electron Microscopy

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The first few weeks of post-natal nerve development is marked by a process known as synaptic elimination. This phenomenon, during which two or more existing axonal branches compete for control of one post-synaptic cell, ends the polyneuronal innervation established in pre-natal life. Neurons rearrange and streamline their connections—dropping redundant periphery connections and strengthening other, more local ones. Though synaptic competition occurs in many areas throughout the nervous system, researchers frequently use samples of the neuromuscular junction (NMJ) for its easy accessibility. The goal of this project is to create a three-dimensional representation of the NMJ, taken from a seven-day-old mouse, using serial transmission electron microscopy (TEM). Ultra-thin sections are cut from a sample block containing NMJs. The two-dimensional slices, each a cross section of the tissue block, are prepared, imaged with a TEM, and captured with a CCD camera. *Reconstruct* software, which uses complex computer algorithms to manipulate image data, allows users to rebuild the high-resolution images in two and three dimensions. Research projects in this area, including this one, aim to uncover the mechanisms that direct synaptic elimination by studying ultrastructural data. With more experience, we would also like to streamline thin section electron microscopy, in the hopes of automating this useful, but time-consuming procedure.

Nanoscale Topography Affects the Biocompatibility of Kidney Cells on Scultpured Thin Films

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The vacuum deposition of parylene forms a coating of uniform thickness. The coating is used as a corrosion resistant barrier for devices. Unfortunately, when deposited normally parylene does not have the desired surface area for cell attachment in biological systems. Recent research by Karuri et al. has shown that cell attachment can be dependent on nanoscale topography. This study focused on depositing parylene Sculptured Thin Films(STFs) which contain nanoscale topography and a desirable increase in surface area for cell attachment. First a suitable chiral structure of parylene STF was developed using computer-controlled substrate rotation during the deposition process. The control allowed the production of the desired shape and thickness. Lithography was then used to pattern silicon topographies of lines and posts ranging in size from 400nm to 20µm. Parylene STFs were deposited on top of the topography and on planar silicon. The kidney cell attachment counts for each substrate type were then examined for differences between conformal parylene coatings on nanoscale and planar topographies and parylene STFs on nanoscale and planar topographies.

Fabrication and Electrical Analysis of Metal Bilayer Electrodes for Nanodevices

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In order to continue the scaling of integrated circuits (ICs), new materials need to be introduced. Metal gates are needed in complementary metal oxide semiconductor (CMOS) technology to reduce the resistivity, depletion effects, and dopant penetration of polysilicon gates. Metal bilayer gates have been proposed to provide adjustable work functions to optimize device performance. Previous work demonstrated how changing the bottom metal thickness could modify the work function. However, the mechanism for this is not clear, and we wish to investigate how the metals affect the work function. In this experiment we are investigating the W/Ti/SiO_2 system with 0.5-3 monolayers of Ti bottom layer thickness. We prepared W/Ti metal bilayer structures on different thicknesses of oxide and fabricated MOS capacitors. From this we determine the work function by measuring the capacitance-voltage characteristics of our capacitors. We then compare the work function behavior of the as-deposited and annealed samples. These results will show if the work function of the metal gate can be determined by very small amounts of Ti at the metal/dielectric interface and clarify the electrical mechanism for this bilayer effect. The ability to control the work function of metal gates will help to enhance the performance of ICs.

The Fabrication and Testing of ZnO Polymer and ZnO Cu_2O Solar Cells

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This research is aimed at creating efficient solid state dye and polymer solar cells. One strategy for increasing the efficiency of the polymer solar cells has been to use nanorods to increase the area of p-n junction of the cell. The increased amount of surface area of the p-n junction will create more split excitons from the absorbed photons, therefore giving a higher quantum yield. If the nanorods have been created with good electrical contacts to the substrate, they will help separate the excited electron from its hole, and conduct that electron to the circuit easier. The focus of this project has been to fabricate zinc oxide nanorods on transparent conducting electrode and use the rods as the n-type semiconductor for a solar cell. Two types of cells with ZnO as the n-type semiconductor were made, an organic polymer and Cu_2O, with these materials as the p-type semiconductors. In both types of cell, the p-type semiconductor lattice will direct contact with the ZnO nanorods. These solar cells will not need an electrolyte to complete the circuit, meaning the entire solar cell will be solid state.

Characterization of Semi-Polar and Non-Polar Gallium Nitride (GaN)

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GaN is a wide, direct band gap material used for optoelectronic and electronic devices. Conventional GaN based structures used for optoelectronic and electronics applications are grown along the polar c-axis. This results in the presence of piezoelectric and spontaneous polarization in the quantum wells. This polarization in the quantum wells reduces the overall performance of conventional optoelectronic devices such as LEDs and lasers. Performance can be potentially improved by growing GaN based quantum wells along the non-polar and semi-polar directions. These quantum wells are either free or almost free from the polarization effects, which thereby promises for increased efficiency and performance of Group-III nitride-based optoelectronic devices. When fabricating these devices, it is extremely important to have high quality films. Defects in the crystalline structure limits device performance. There are two main methods used for characterizing these films, x-ray diffraction and atomic force microscopy. X-ray diffraction is used to analyze the crystallographic structure and composition of the films. Atomic force microscopy takes nano-scale topographical images of the films. This can be used to find sub-micron defects and surface roughness in the film. Once the film quality and composition is verified, devices are fabricated and electrically and optically characterized. These characterizations help optimize the properties of the semipolar and nonpolar GaN, which provides better fabrication of devices.

Nanoscale Gray-Scale Lithography And Pattern Transfer

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The relevance of gray-scale lithography is a consequence of demand for applications in optics, nanoimprinting, and M/NEMS (micro/nano-electromechanical systems). M/NEMS requires 3-D structures for mechanical motion, whereas conventional lithographic techniques are optimized for binary, or 2-D, patterns. Two primary methods of gray-scale patterning currently exist: use of a gray-scale mask in optical lithography or a direct write electron-beam lithography (EBL) system. Each creates a 3-D resist profile by varying the incident energy at different locations of the resist, thus producing differential solubility rates. These features can be further amplified (and transferred) to the substrate through deep reactive ion etching. Our goal, through EBL, is to produce a blazed grating, a diffractive optical device sensitive to a single peak wavelength upon incident polychromatic light. Such a design requires a saw tooth profile, very much feasible through our EBL system. Limitations of EBL arise out of proximity effects, where electrons expose patterns far away from their point of incidence. A proximity correction method is employed to achieve the ideal design.

Partially Self-Assembled Planar Photonic Structures

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Waveguides, which are planar photonic structures, use the principles of refractive index contrast to propagate light in a desired path. One of the major problems with current waveguides is optimizing the efficiency. Various sources for loss in waveguides exist, including side wall roughness which results in scattering. The motivation behind this project is to improve the efficiency of waveguides by eliminating surface roughness, without implementing a complex process. We fabricated new smooth waveguides by exploiting the surface tunability of a silicon wafer using patterned hydrophobic and hydrophilic regions. The hydrophilic regions were a film of 5.6 microns of oxide, while the monolayer FOTS was used to make the hydrophobic areas. Norland Optical Adhesive 71 (n= 1.56) was used as the waveguide material. The adhesive, when applied in a very thin, uniform layer, selectively forms on the hydrophilic lines and dewets from the hydrophobic surroundings. The waveguides were found to have a lens-shaped cross section with a ratio of 10:1 width to height by SEM. These waveguides were indeed smoother than the current technology by observation using SEM and AFM. They were also coupled with an optical fiber and successfully guided light with a measurable output. Waveguides of various lengths were measured to calculate the loss vs. length. Loss results are still in progress.