The 2009 NNIN REU Convocation

University of Michigan
August 9-12, 2009

LNF
Lurie Nanofabrication Facility
University of Michigan

NNIN
Nanoscale Science, Engineering & Technology

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2009 NNIN REU Convocation
University of Michigan • August 9-12, 2009

Sunday, August 9th

5:30 p.m., The A Maize-ing Race — Start at Baits Dorms
7 p.m., Pizza Welcome Dinner — CSE Tishman Hall

Monday, August 10th

8 a.m., Breakfast — EECS Atrium

9 a.m., Welcome – Professor K. Najafi ... EECS 1500

Session M1-A, Room EECS 1500 ... Sandrine Martin

9:20 a.m., Alexander Sharenko (Arizona State); **page 8**
"Optimization of Tunnel Diodes in Multi-Junction Solar Cells"

9:34 a.m., Menooa BadaliansVanigh (Howard); **page 9**
"Growth of CuIn(Ga)Se_2 Thin Film Solar Cells"

9:48 a.m., Jasmine Banks (U Mich); **page 10**
"Zn Diffusion for High Sensitivity InGaAsN Photodetectors"

10:02 a.m., James Mueller (UT Austin); **page 11**
"Semiconductor Nanocrystal Inks for Printed Photovoltaics"

Session M1-B, Room EECS 1200 ... Mike Deal

9:20 a.m., Barbara Raynal (Stanford); **page 12**
"Nano-Magnetic Particles for Cancer Diagnostics"

9:34 a.m., Sweta Sengupta (Stanford); **page 13**
"Artificially-Manufactured SERS-Active Nanoparticles for Cancer Diagnostics"

9:48 a.m., Arjunen Kutayiah (UCSB); **page 14**
"Characterization of Thermally Induced Bilayer Structural Distortions"

10:02 a.m., Margaret Merritt (UCSB); **page 15**
"Nanomechanical Properties of Motor Proteins"

10:16 a.m., Break — EECS Atrium

Session M2-A, Room EECS 1500 ... Ethan Allen

10:45 a.m., Amanda Oehrlein (Cornell); **page 16**
"Characterization and Acid Diffusion Studies of Cyclodextrin and its Carborane Inclusion Complex"

10:59 a.m., Kevin Donaher (Penn State); **page 17**
"Morphology Development and Properties of Thin-Film Polymers"

11:13 a.m., **Jamal Molin (Stanford);** **page 18**
"Characterization of the Diffusitivity of Conductive Polymers in Nanochannel Confinement"

11:27 a.m., Alexandra Machen (U Washington); **page 19**
"Characterization of Gold Nanoparticles Functionalized with Thiolated Single-Stranded DNA"

11:41 a.m., Alexandra Rutz (WUSTL); **page 20**
"Synthesis and Properties of Manganese Oxide Nanoparticles for Environmental Applications"

Session M2-B, Room EECS 1200 .... Bart VanZeghbroek

10:45 a.m., Matthew Hershberger (Colorado); **page 21**
"Fabricating Mechanically-Adjustable Single-Molecule Electrical Contacts"

10:59 a.m., Lydia Kisley (Colorado); **page 22**
"Integration of Gallium Nitride Nanowires With Silicon Circuits"

11:13 a.m., Benjamin McPheron (Colorado); **page 23**
"Process Development for a Traveling Wave Terahertz Detector"

11:27 a.m., Athena Pan (Harvard); **page 24**
"Visible Optical Properties of Pulse-Laser-Melted Silicon Implanted with S, Se, Te, B, P and As"

11:41 a.m., Paden Roder (Harvard); **page 25**
"Fabrication of a Stable Tunable Quantum Hall Interferometer in the Fractional Quantum Hall Regime"

11:55 a.m., Lunch and Photo Sessions EECS Atrium

1:45 p.m., 2nd Year REU Program, Lynn Rathbun ....EECS 1500

Session M3-A, Room EECS 1500 ....Katie Hutchinson

2:25 p.m., Laura Gaskins (Georgia Tech); **page 26**
"Innovative Imprint Lithography for Chip-to-Chip Connections"

2:39 p.m., Richard Frnka (WUSTL); **page 27**
"Pattern Deposition of Nanoparticles of Different Shapes by Aerosol Route"

Session M3-B, Room EECS 1200 .... Ronald Redwing

2:25 p.m., Meredith Henstridge (Colorado); **page 28**
"3D Photonic Crystals Fabricated Through Direct Laser Writing"

2:39 p.m., Katherine Kragh (Penn State); **page 29**
"Advancing Energy-Efficient Solid State Lighting through Nanotechnology"

2:53 p.m., Break EECS Atrium

Session M4-A, Room EECS 1500 **Stefan Myhajlenko**

3:20 p.m., Claire McLellan (Arizona State); **page 30**
"Single Walled Carbon Nanotubes for DNA Translocation"

3:34 p.m., Stephanie Bojarski (Stanford); **page 31**
"Imaging and Characterization of Carbon Nanotube Growth and Transfer"

3:48 p.m., Alexander Hryn (U Mich); **page 32**
"Horizontally Aligned Carbon Nanotube Composite Beams"

4:02 p.m., Mark Borysiak (UT Austin); **page 33**
"Graphene Synthesis on Copper Substrates using Chemical Vapor Deposition"

Session M4-B, Room EECS 1200 .... Melanie-Claire Mallison

3:20 p.m., Scott Isaacson (Cornell); **page 34**
"Atomic Layer Deposition on Surfaces Modified by Thin Interfacial Organic Layers"

3:34 p.m., John Abrahams (Howard); **page 35**
"Magnetron Sputtering and Characterization of Ag-Si for Infrared Photodetectors"

3:48 p.m., Rachel Hoffman (U Minn); **page 36**
"Materials for CZTS Photovoltaic Devices"

4:02 p.m., Ian Braly (U Washington); **page 37**
"Space-Charge Limited Current Calculations in Nanowires"

4:16 p.m., Tours of Lurie Nanofabrication Facility (optional)

4:30 p.m., Go to dorms/bus stop/central campus
(regular campus bus lines – Northwood or Commuter Southbound)

5:00 p.m., Free Time at Museum of Natural History

7:00 p.m., Dinner at Palmer Commons – Glass House Café

8:30 p.m., Free Time on Central Campus
As needed, Buses back to North Campus (regular campus bus lines – Northwood or Commuter Northbound)

Tuesday, August 11th.. .. ..

8 a.m., Breakfast EECS Atrium
Announcements *EECS Atrium*

Session T1-A, Room EECS 1500..Angela Berenstein

9:05 a.m., Julie Bellfy (Cornell); **page 38**
"Cyclic Charging of Reduction-Oxidation (redox) Markers in Metal-Oxide-Semiconductor Capacitors"

9:19 a.m., Ian Walsh (Cornell); **page 39**
"Ohmic Contact Study for Gallium Nitride-Based HEMTs and Ultra-Short N-Type THz Devices"

9:33 a.m., Sarah Reiff (UCSB); **page 40**
"Magneto-Transport in Photoexcited Diamond"

9:47 a.m., Lorraine Weis (UCSB); **page 41**
"III-V MOSFET Fabrication"

Session T1-B, Room EECS 1200 .... Kathryn Hollar

9:05 a.m., Tyler Cain (Harvard); **page 42**
"Materials Studies on La0.6Sr0.4Co0.8Fe0.2O3-? Cathodes for Solid Oxide Fuel Cells"

9:19 a.m., Katherine Kragh (Penn State); **page 43**
"Metallization for High Temperature Electronics"

9:33 a.m., Denys Zhuo (Penn State); **page 44**
"Fracture at the Nanoscale"

9:47 a.m., Devanand Sukhdeo (UT Austin); **page 45**
"Large-Scale Chemical Vapor Deposition Growth of Graphene over Thin Films of Cobalt"

10:01 a.m., Break EECS Atrium

Session T2-A, Room EECS 1500 .... James Griffin

10:30 a.m., Ericka Cottman (Arizona State); **page 46**
"Nanotextured Surfaces: New Generation Bioelectronic Interfaces for Nanomedicine"

10:44 a.m., Lilian Gong (Arizona State); **page 47**
"Nanoporous Surfaces: Bioelectric Interfaces for Pathogen Detection"

10:58 a.m., Adam Kozak (Georgia Tech); **page 48**
"Optical Detection of Thrombosis Formation Within a Microfluidic Device using a Helium-Neon Laser as a Radiation Source"

11:12 a.m., Hamsa Sridhar (Georgia Tech); **page 49**
"Development of a Multiplex CARS Flow Cytometer for Label-Free, Real-Time Classification"

11:26 a.m., Theresia Monikang (Howard); **page 50**
"Using Molecular Self-Assembly for Surface Charged Monolayers to Control Bio-Assembly"

Session T2-B, Room EECS 1200 .... Lynn Rathbun

10:30 a.m., Isaac Markus (Cornell); **page 51**
"Development and Fabrication of a Micro-Microbial Fuel Cell (mMFC)"

10:44 a.m., Ellen Sedlack (Cornell); **page 52**
"Development of an Intravessel Xylem Probe for Viniculture and Forest Ecology"

10:58 a.m., Nicolas Shillingford-Cordero (U Mich); **page 53**
"Microfluidic Single Cell Assay Chip for Cancer Efficacy Tests"

11:12 a.m., Nathaniel Hogrebe (WUSTL); **page 54**
"Nanostructured Scaffolds for Tissue Engineering Applications"

11:26 a.m., Angela Horst (WUSTL); **page 55**
"Antimicrobial Effects of Metal Oxide Nanoparticles"

11:40 a.m., Box Lunch and Wave Field — EECS Atrium / Outside
Admin meeting for Coordinators — *EECS 1340*

1:20 p.m., SEI Discussions, Moderators: Ethan Allen, Mike Deal, Brandon Lucas

EECS 1500 / EECS 1200 / EECS 1003

Session T3-A, Room EECS 1500 .... Sandrine Martin

2:14 p.m., Julia Sokol (Georgia Tech); **page 56**
"Microfabrication of Heaters and Resistance Thermal Detectors for Simulation of Hotspots"

2:28 p.m., Gabrielle Castillo (Howard); **page 57**
"Fabrication and Design of Nanowire Transistors"

Session T3-B, Room EECS 1200 .... Becky VonDissen

2:00 p.m., Michael Zakrewsky (WUSTL); **page 58**
"Fabrication, Characterization and Modeling of a Novel Optofluidic Biosensor"

2:14 p.m., Alayne Lawrence (U Minn); **page 59**
"Fabrication of Sub-Micron Lateral Spin Valves"

2:28 p.m., Daryl Spencer (UCSB); **page 60**
"Hybrid Silicon Microring Lasers"

2:42 p.m., Break — EECS Atrium

Session T4-A, Room EECS 1500 .... Angela Berenstein

3:10 p.m., **Christine Burdett (Arizona State);** page 61
"Fabrication and Characterization of Catalytic Nanomotors"

3:24 p.m., **Steven Brown (Colorado);** page 62
"Residual Stress of Atomic Layer Deposited Tungsten"

3:38 p.m., **Jake Sadie (Georgia Tech);** page 63
"Optimization and Bioconjugation of Silicon Nanowire Biosensors"

3:52 p.m., **Vivian Feig (Stanford);** page 64
"Energy Recoverable Operation of Lateral Nanoelectromechanical (NEM) Aluminum Switches"

Session T4-B, Room EECS 1200 .... Brandon Lucas

3:10 p.m., **Keara Harris (Howard);** page 65
"The Growth of Silicon, Germanium, SixGe1-x and various Polytypes of Silicon Carbide Nanowires"

3:24 p.m., **Du Nguyen (U Mich);** page 66
"Atomic Layer Deposition of High-k Gate Dielectrics for Thin Film Transistors"

3:38 p.m., **Axel Palmstrom (U Minn);** page 67
"Fabrication of Nanohole Arrays Using Nano-Imprint Lithography"

3:52 p.m., **Arrielle Opotowsky (UT Austin);** page 68
"Elemental Analysis of Ge-SixGe1-x Core-Shell Nanowire Heterostructures"

4:06 p.m., Change into picnic clothes

4:30 p.m., Bus from Baits to Gallup Park (starting at 4:30 p.m., back and forth trips as needed)
Canoe Rentals

7 p.m., Picnic

8 p.m., Bus from Gallup Park back to Baits (starting at 8 p.m., back and forth trips as needed)

Wednesday, August 12th .. ..

8 a.m., Breakfast — EECS Atrium

9:00 a.m., Announcements — EECS Atrium

Session W1-A, Room EECS 1500 .... Kathryn Hollar

9:05 a.m., **Tiffany Moeller (Cornell);** page 69
"Microfluidics Guided Self-Assembly of Liposomes"

9:19 a.m., **Edgar Garay (Georgia Tech);** page 70
"Fabrication of Grating Couplers and Optical Waveguide Sensors"

9:33 a.m., **Arolyn Conwill (Harvard);** page 71
"Fabrication and Characterization of Nanobeam Resonators with Waveguides"

9:47 a.m., **Takia Wheat (Harvard);** page 72
"Fabrication of Silicon Nitride Waveguides"

10:01 a.m., **Matthew Strathman (Stanford);** page 73
"Silicon Migration for Nanophotonic Elements"

Session W1-B, Room EECS 1200 .... Jean Toll

9:05 a.m., Stephanie Lau (U Washington); page 74
"Modeling Intermediates in Prion Protein Fibril Formation"

9:19 a.m., Eric Hao (Penn State); page 75
"Raman Topography Studies of Eutectic Systems of Strontium Ruthenate (214) and Ruthenium"

9:33 a.m., Travis Rosmus (Penn State); page 76
"Pillar Array Polymer Template for Solar Cells"

9:47 a.m., Chelsea Frid (U Mich); page 77
"Plasmonic Focusing of Light"

10:01 a.m., Jacqueline Collette (U Washington); page 78
"Atomic Force Microscope Direct-Write of Carbon Nanowires: Structure Optimization"

10:15 a.m., Break
Poster Set up *EECS Atrium*

10:45 a.m., Science and Art Panel, Moderator: Sandrine Martin ....EECS 1500

Session W2-A, Room EECS 1500.. Melanie-Claire Mallison

11:40 a.m., Sarah Connolly (U Minn); page 79
"Role of Reactive Oxygen Species in Nanotoxicity"

11:54 a.m., Alyssa Terry (U Minn); page 80
"DNA Electrophoresis in Sparse Ordered Obstacle Arrays"

Session W2-B, Room EECS 1200 .... Amy Sears

11:40 a.m., Keith Olson (U Washington); page 81
"Engineering Hcp1 Protein Nanotubes for Non-specific DNA Binding"

11:54 a.m., Richard Purvis (UT Austin); page 82
"Controlling Cell Functions with Light on Tip"

12:08 p.m., Lunch / Beginning of Poster Session ....EECS Atrium

12:30-1:15 p.m., Group A stays at poster
1:15-2 p.m., Group B stays at poster
2 p.m., Final Remarks / Adjourn EECS Atrium

6 p.m., Open Session at Pinball Pete Arcade (free, up to 2 hours)
1214 S University Ave, (Central Campus)

Departure

Preferentially Thursday, August 13th
Dorm checkout at noon 8/13/09
Shuttles provided to interns (Dorms -> Airport)

Convocation Abstracts In Session Order

IN ALPHA ORDER BY LAST NAME:

Optimization of Tunnel Diodes in Multi-Junction Solar Cells

Alexander Sharenko
Materials Science and Engineering, Georgia Institute of Technology

NNIN REU Site: Center for Solid State Electronics Research, Arizona State University
NNIN REU Principal Investigator(s): Dr. Yong-Hang Zhang, Electrical Engineering, Arizona State
NNIN REU Mentor(s): Dr. Kevin O'Brien, Electrical Engineering, Arizona State University
Contact: alexsharenko@gmail.com, yhzhang@asu.edu

Multi-junction (MJ) solar cells consist of several photovoltaic cells stacked vertically with each distinct cell connected via a tunnel diode (TD). TDs are highly doped p-n diodes which allow for quantum mechanical tunneling through their narrow depletion regions at low bias voltages. TD junctions serve a vital role in MJ solar cells as they provide a relatively optically transparent, low resistance, lattice-matchable means of transferring current from one cell to the next.

The focus of this project was to investigate whether a wait time between epitaxial growth of n and p-doped layers could introduce performance enhancing defects into the depletion region of GaAs TDs. Such defects have been shown to improve peak tunneling current density via defect-assisted tunneling. The samples were characterized using I-V measurements from 80 to 300 K and analyzed with a theoretical model. Peak tunneling current densities were measured to be in the range of 2.48 to 5.08 mA/cm^2, less than the A/cm^2 order of magnitude needed for incorporation into high efficiency MJ solar cells. Additionally, increased wait time corresponded to progressively lower values.

These results suggest the tested TDs only exhibit band-to-band tunneling and that any incorporated defects only increased the electrical resistance of the TDs.

Growth of $CuIn(Ga)Se_2$ Thin Film Solar Cells

Menooa BadalianVanigh
Computer Engineering, Glendale Community College

NNIN REU Site: Howard Nanoscale Science and Engineering Facility (HNF), Howard University
NNIN REU Principal Investigator(s): Dr. Gary L. Harris, HNF, Howard University
NNIN REU Mentor(s): Mr. James Griffin, HNF, Howard University
Contact: menooa@hotmail.com, gharris@msrce.howard.edu

Copper indium diselenide ($CuInSe_2$) and copper indium gallium diselenide ($CuInGaSe_2$) thin film solar cells deposited by spray pyrolysis are a low cost way to provide solar energy. Although they are relatively cheap to fabricate, they suffer from low efficiencies because of their small grain sizes. In this work, we investigated the conditions of growth rate and temperature in order to obtain stoichiometric layers of these materials. We also investigated the conditions necessary to grow cadmium sulfide (CdS) by the chemical bath technology, which will be used as the n-type contact for our solar cell structure. Employing cadmium sulfide also increases the photovoltaic solar efficiency of our tandem structure. Finally, we sought to determine if grain sizes can be increased by rapid thermal annealing of the grown layers. $CuInSe_2$ films were grown on a soda lime glass substrate coated with 150 nm of molybdenum at 350-400ºC for 30-60 minutes.

Electron dispersive spectroscopy data for $CuInSe_2$ and CdS indicated the presence of all elements. Scanning electron microscopy and optical microscopy indicated uniform growth of CdS films but non-uniform growth for $CuInSe_2$. We are presently fabricating the actual solar cell and will report these results.

This work is supported by the National Science Foundation through the National Nanotechnology Infrastructure Network Research Experience for Undergraduates (NNIN REU) Program.

Zn Diffusion for High Sensitivity InGaAsN Photodetectors

Jasmine Banks
Electrical Engineering, Virginia Commonwealth University

NNIN REU Site: Lurie Nanofabrication Facility, University of Michigan, Ann Arbor

NNIN REU Principal Investigator(s): Rachel S. Goldman, Department of Materials Science and Engineering (MSE), University of Michigan, Ann Arbor, MI

NNIN REU Mentor(s): Yu Jin, Departments of Physics and MSE, University of Michigan, Ann Arbor, MI

Contact: banksjl@vcu.edu, rsgold@umich.edu

The sensitivity of solid-state photodetectors is often limited by surface leakage current along the etched/cleaved side wall under reverse bias voltage. A significant reduction in leakage current was recently reported for InGaAsN, using epitaxial growth of an n-i-n structure, followed by spatially selective type conversion during metal-organic chemical vapor deposition re-growth using dimethylzinc and diethylzinc. The etched/cleaved surface is thus surrounded by the n-type layer and no longer under bias.

In this work, we propose a novel *ex-situ* Zn diffusion approach to type conversion of n-i-n diodes. Using a commercially-available Zn-containing spin-on-glass (SOG), we are adapting the type conversion approach to molecular-beam epitaxially grown InGaAsN-based photodetectors, intended for operation in the 1.3 µm to 1.55 µm wavelength range. In this summer project, we are examining the influence of the Zn SOG surface processing and thermal annealing treatments on the depth-profile of electrically active Zn using electrochemical CV and Hall measurements.

We will discuss the (In)GaAs(N):Zn diffusivity as a function of annealing time and temperature and its impact on the photodetector responsivity.

Semiconductor Nanocrystal Inks for Printed Photovoltaics

James Mueller
Chemical Engineering, University of Michigan – Ann Arbor

NNIN REU Site: Microelectronics Research Center, The University of Texas at Austin
NNIN REU Principal Investigator(s): Brian Korgel, Chemical Engineering, University of Texas
NNIN REU Mentor(s): Matthew Panthani, Chemical Engineering, University of Texas
Contact: jamesmue@umich.edu, korgel@che.utexas.edu

Solution-processing of electronic devices provides an excellent opportunity to reduce material and manufacturing cost by eliminating energy-intensive production methods and increasing materials utilization. In this study, we make solution-processed copper indium gallium selenide (CIGS; $Cu(In_XGa_{1-X})Se_2$) solar cells.

These devices are comprised of several layers, all of which are solution-processed from colloidal nanocrystals. Conventional CIGS solar cells (made through vapor deposition and sputtering of metal or semiconductor targets) typically have a stacked structure of metal back electrode, semiconducting layers, and a transparent conductive oxide top contact such as indium-tin oxide (ITO). Rather than sputtering or evaporating, we sprayed dispersions of nanocrystals using an airbrush purchased from a local art supply store.

In this study, we used a back contact of Au nanoparticles synthesized via the Brust method (Brust et al, J. Chem. Soc., Chem. Commun., 1994, 861) dispersed in toluene. CIGS nanocrystals were synthesized using a procedure developed by Panthani and coworkers (Panthani et al, *J. Am. Chem. Soc.*, 2008, 130 (49), pp 16770–16777) as a precursor to a sprayed p-type absorber layer. Two n-type layers were synthesized: one from CdS nanorods synthesized via a method reported by Shieh and coworkers (Shieh et al, *J. Phys. Chem. B*, 2005, 109 (18), pp 8538–8542), and a second from ZnO nanoparticles synthesized via Greene and coworker's method (Greene et al, *Nano Lett.*, 2005, 5 (7), pp 1231–1236).

A transparent conducting top electrode was fabricated using ITO nanoparticles purchased from Sigma-Aldrich diluted in isopropanol. Devices were prepared on both glass and flexible plastic substrates and annealed in a tube furnace or a on a heating stage. The power conversion efficiency and external quantum efficiency of the completed devices were tested to assess the feasibility of implementing devices made in this manner.

Nano-Magnetic Particles for Cancer Diagnostics

Barbara D. Raynal
Electrical Engineering, University of Notre Dame

NNIN REU Site: Stanford Nanofabrication Facility, Stanford University

NNIN REU Principal Investigator(s): Shan X. Wang, Materials Science, and Electrical Engr, Stanford University

NNIN REU Mentor(s): Mingliang Zhang, Materials Science, Stanford University; Robert Wilson, Materials Science, Stanford University; Mary Tang, Stanford Nanofabrication Facility Staff

Contact: braynal.at.nd.edu, sxwang.at.stanford.edu

Nano-magnetic particles can be used to detect cancer cell markers in biological fluids. Cancer proteins are tagged with magnetic particles to identify cancer proteins since magnetism is rare in biological systems. The objective of this work is to create nano-magnetic particles of varying sizes that can be used to study the detection of different kinds of cancer cells. There are several steps.

First, a monolayer of polymer nanospheres is spincoated onto a Si wafer. The nanospheres are then etched and used as a mask to create a template consisting of tiny pillars. A second Si wafer is then coated with PMGI and PMMA. The template is imprinted onto the PMMA layer of the second wafer to create many holes the size of the pillars. Next, the PMGI layer is etched with LDD26W to create deeper holes, followed by metal deposition. The metal falls into the holes and nanoparticles the size of the etched nanospheres are created.

We will see how by varying the etching parameters it is possible to create templates with different pillar size ranging from 50 to 200 nm which in turn vary the size of the nanoparticles that are used for detecting different kinds of cancer cells.

Artificially-Manufactured SERS-Active Nanoparticles for Cancer Diagnostics

Sweta Sengupta
Biology and Computer Science, Emory University

NNIN REU Site: Stanford Nanofabrication Facility, Stanford University

NNIN REU Principal Investigator(s): Dr. Shan Wang, Material Science and Electrical Engr, Stanford University

NNIN REU Mentor(s): Dr. Jung-Sub Wi, MSE, Stanford University; Dr. Robert Wilson, MSE, Stanford University; Dr. Mary Tang, Stanford Nanofabrication Facility, Stanford University

Contact: ssengu2@emory.edu, sxwang@stanford.edu

Surface-enhanced Raman scattering (SERS) is a powerful method for examining biological samples. Antibody marked SERS-active nanoparticles can be used in human serum bioassays to detect cancer cells. We are creating SERS nanoparticles that are designed for enhancing a local electromagnetic field to increase the Raman signal and will be fabricated by nanoimprint lithography, thin film Ag deposition, and release of nanoparticles from substrate.

We will utilize a nanoimprint stamp, which is created by using a polystyrene spin coated silicon wafer and its selective plasma etching process. Scanning electron microscope (SEM) and Raman spectroscopy will determine whether we have created nanoparticles worthy of diagnosing cancer.

Characterization of Thermally Induced Bilayer Structural Distortions

Arjunen (Ryan) Kutayiah
Physics, City University of New York Hunter College

NNIN REU Site: Nanotech @ UCSB, University of California Santa Barbara

NNIN REU Principal Investigator(s): Deborah K. Fygenson, Physics & Biomolecular Science & Engineering Program, University of California Santa Barbara

NNIN REU Mentor(s): Kimberly Weirich, Biomolecular Science & Engineering, UCSB

Contact: arjunenryankutayiah@hotmail.com and deborah@physics.ucsb.edu

Supported lipid bilayer (SLB) is a promising biologically inspired surface coating and model system for reconstructing membrane processes. We apply thermal stress to SLB and report on the resulting structural distortions. Thermal stress induces long, thin, flexible protrusions (worms) in the SLB that are unstable and eventually collapse into giant vesicles. We examine the rigidity, length distribution, and collapse of SLB worms as a means toward better understanding the material properties of SLB.

Nanomechanical Properties of Motor Proteins

Margaret Merritt
Biomedical Engineering, Brown University

NNIN REU Site: Nanotech @ UCSB, University of California Santa Barbara

NNIN REU Principal Investigator(s): Megan T. Valentine, Mechanical Engineering, University of California at Santa Barbara

NNIN REU Mentor(s): Dezhi Yu, Mechanical Engineering and Materials Science, University of California at Santa Barbara

Contact: Margaret_Merritt@brown.edu, valentine@engineering.ucsb.edu

Motor proteins drive essential processes in the body, including muscle movement and cell division. Currently, the relationship between the structure and function of these molecular motors is not well understood. Creating nanoscale motor proteins with tunable properties could lead to vast improvements in cancer and disease research as well as fundamental insight into the biology of motor proteins. Therefore, the present study aims to further investigate nanomechanical properties of kinesin, one type of motor protein that is responsible for intracellular transport.

To accomplish this, human kinesin, labeled with green fluorescent protein and a histidine epitope tag, was successfully generated by expression in bacteria and characterized using fluorescence microscopy. Functionality and motility experiments were performed to test the interaction between kinesin and microtubules, the cytoskeletal filaments along which kinesin motors walk. A total internal fluorescence microscopy system was developed and refined to achieve single molecule imaging of kinesin.

The design plan for expression and characterization that was established will enable future analysis of a wide variety of motor proteins.

Characterization and Acid Diffusion Studies of Cyclodextrin and its Carborane Inclusion Complex

Amanda Oehrlein
Chemistry, Hamline University

NNIN REU Site: Cornell NanoScale Science & Technology Facility, Cornell University

NNIN REU Principal Investigator(s): Christopher Ober, Materials Science, Cornell University

NNIN REU Mentor(s): Marie Krysak, Chemistry, Cornell University; Jing Sha, Materials Science, Cornell University

Contact: ao252@cornell.edu, cober@ccmr.cornell.edu

In order to move forward, the semiconductor industry is dependent on improvements in the lithographic process, most importantly the development of new resist materials. As pattern dimensions continue to decrease, issues of line edge roughness arise. Molecular glasses are an attractive alternative to polymeric resists, as they are able to incorporate an amorphous structure and high T_g with a small size that can show improved line edge roughness.

Cyclodextrin has shown promise as a 193 nm resist, though it exhibits poor etch resistance. By introducing carborane into the cyclodextrin core, we have shown that the etch resistance of cyclodextrin is around that of PHOST, an industry standard photoresist. However, we also see an increase in line edge roughness. We intend to observe the differences in acid diffusion between the non-carborane and carborane resist by creating bilayers and measuring film thicknesses before and after development.

Using this data, we can now modify cyclodextrin core with carborane to inhibit acid diffusion and show improved patterning capability with high etch resistance.

Morphology Development and Properties of Thin-Film Polymers

Kevin Donaher
Department of Physics, Bard College at Simon's Rock

NNIN REU Site: Penn State Nanofabrication Facility, The Pennsylvania State University

NNIN REU Principal Investigator(s): Stephanie A. Petrina, Michael A. Hickner, Department of Materials Science and Engineering, Penn State University

In order to function, a proton exchange membrane fuel cell (PEMFC) requires a membrane that selectively allows for the passage of protons, while remaining electrically insulating. One way to accomplish the required proton transport is to use a sulfonated self-assembling block copolymer. The negative charge of the sulfonate groups should cause the desired selective permeability for the positively charged protons and the high density of sulfonate groups in a block copolymer is targeted towards achieving high conductivity.

It is likely that the morphology of the film affects the conductivity, however, before the conductivity-morphology connections can be determined, there must be a reliable way of inducing and monitoring the phase behavior of sulfonated polymers. Our work seeks to test ways to control the morphology of the films and to use field emission scanning electron microscopy an atomic force microscopy to characterize the resulting structures. Previous studies have shown that it is possible to anneal unsulfonated films with heat or solvent to achieve more ordered morphologies.

With unsulfonated poly(hexyl methacrylate)-b-poly(styrene)-b-poly(hexyl methacrylate) (PHMA-b-PS-b-PHMA) triblock copolymer film, we observed a transition from a disordered morphology in the as-cast state to lamellar and cylindrical morphologies after annealing. For the sulfonated triblock PHMA-PS-PHMA films, thermal annealing and vapor annealing with DMF did not produce a noticeable change in the morphology of the as-cast film.

It is hypothesized that the strong ion pairing interactions of the sulfonates and high T_g of the sulfonated phase prevents the block copolymer from forming an ordered morphology. From this project we expect to gain experience with polymers, lab safety, experimental and clean room procedures, and characterization equipment.

Characterization of the Diffusitivity of Conductive Polymers in Nanochannel Confinement

Jamal Lottier Molin
Computer Engineering, University of Maryland, Baltimore County

NNIN REU Site: Stanford Nanofabrication Facility, Stanford University
NNIN REU Principal Investigator(s): Reinhold H. Dauskardt, Materials Science and Engr, Stanford University
NNIN REU Mentor(s): Taek-Soo Kim, Materials Science and Engineering, Stanford University
Contact: dauskardt@stanford.edu, tskim1@stanford.edu

The fabrication of nanochannels for analyzing molecular behavior at the single-molecule level is a rising phenomenon in material science. This methodology has been applied in research areas including the controlled transport of biological species, NEMS (nanoelectromechanical systems) studies, and the stabilization of the release rates of small molecules in drug delivery.

Interest in the distinctive mechanical, electrical, and optical properties of the conductive polymer PEDOT:PSS, poly (3, 4-ethylenedioxythiophene) poly (styrenesulfonate), widely used in organic electronics such as sensors, solar cells, and LEDs, induces further research concerning this molecule under a nano-confining environment.

In this work, we will fabricate nanochannels on a quartz substrate using electron beam lithography, and furthermore, use these nano-devices to characterize the diffusitivity of PEDOT:PSS. Observation under an optical microscope will allow for characterization of the molecule's diffusitivity, while images obtained from the SEM will confirm existence of these molecules confined in the nanochannels. The ability to characterize PEDOT:PSS in such nano-confinement will impose a strong foundation on further research on this conductive polymer.

Characterization of Gold Nanoparticles Functionalized with Thiolated Single-Stranded DNA

Alexandra J. Machen
Chemical Engineering, University of Kansas

NNIN REU Site: Center for Nanotechnology, University of Washington, Seattle

NNIN REU Principal Investigator(s): David G. Castner, Bioengineering and Chemical Engineering, University of Washington

NNIN REU Mentor(s): Sirnegada Techane, Chemical Engineering, University of Washington

Contact: jaymac@ku.edu, castner@nb.engr.washington.edu

Gold surfaces functionalized with deoxyribonucleic acid (DNA) are used in biomedical applications such as biosensing. When biosensors and other biomedical devices are placed in a biological environment, various reactions (analyte sensing, protein adsorption, etc.) will occur at their surface since the surface is the interface with the biological system. Thus, to develop an understanding of the structure-function relationship for biomedical devices and optimize their performance, their surface properties must be characterized. For nanoparticles, where the surface-to-volume ratio is high, these surface properties are crucial and often unique from their larger scale counterparts.

Our work included functionalizing and characterizing 14 nm diameter gold nanoparticles (AuNPs) with thiolated single-stranded DNA (SH-ssDNA) in various buffers with different salt concentrations. We performed detailed surface analysis of the functionalized AuNPs using x-ray photoelectron spectroscopy (XPS) to determine the optimal conditions for SH-ssDNA assembly. These SH-ssDNA functionalized AuNPs were then backfilled with hydroxyl-terminated alkylthiols. The backfill time was varied to obtain optimal SH-ssDNA hybridization properties.

Other characterization techniques used included transmission electron microscopy (TEM) to determine the size, shape and size distribution of the AuNPs, and UV/VIS to determine the stability of AuNPs. Contol flat gold surfaces were also functionalized with SH-ssDNA for comparison to the functionalized AuNPs.

Synthesis and Properties of Manganese Oxide Nanoparticles for Environmental Applications

Alexandra Rutz
Chemistry and Molecular & Cellular Biology, University of Illinois Urbana-Champaign

NNIN REU Site: Nano Research Facility, Washington University in St. Louis, MO

NNIN REU Principal Investigator(s): Young-Shin Jun, Energy, Environmental, and Chemical Engineering, Washington University in St. Louis

NNIN REU Mentor(s): Young-Shin Jun, Energy, Environmental, and Chemical Engineering, Washington University in St. Louis

Contact: arutz2@illinois.edu, ysjun@seas.wustl.edu

Manganese oxide nanoparticles can be utilized for advanced materials in battery materials, nanoelectronics, and biomedical applications. To have more efficient and well-controlled performance, these materials need particles of well-defined size, while remaining benign to humans and environment.

In this work, we synthesized nanoparticles with a biomineralization approach and investigated their toxicity. Manganese oxide nanoparticles were synthesized using iron storage protein ferritin that provides an 8 nm cavity in which these particles form.

We compared the sizes and morphologies of biomimetically synthesized manganese oxide nanoparticles to those from inorganic synthesis using dynamic light scattering (DLS), transmission electron microscopy (TEM), high resolution TEM (HR-TEM), and atomic force microscopy (AFM). DLS showed sizes of particle aggregates as a function of reaction time and aqueous conditions. Electron diffraction patterns were collected by HR-TEM to identify the phase of nanoparticles and determine particle size. AFM was used to investigate morphologies and sizes of the particles. For toxicity studies, three bacteria—*E. coli*, mycobacteria, and Shewanella —were studied while in solution with manganese oxide nanoparticles. The nanoparticles studied were those synthesized via inorganic synthesis and those via biomineralization.

Our findings from this work will provide fundamental information of the potential toxicities of nanoparticles generated by different pathways.

Fabricating Mechanically-Adjustable Single-Molecule Electrical Contacts

Matthew Hershberger
Department of Physics, Bethel College, Kansas

NNIN REU Site: Colorado Nanofabrication Laboratory, University of Colorado at Boulder

NNIN REU Principal Investigator(s): Charles Rogers, Department of Physics, University of Colorado at Boulder

NNIN REU Mentor(s): Jason Gray, Department of Physics, University of Colorado at Boulder

Contact: matthewher@bethelks.edu, Charles.Rogers@Colorado.edu

We investigated the fabrication parameters for mechanically-adjustable break junctions on a phosphor bronze substrate. Mechanically-adjustable break junctions have applications in studying the electron transport of molecules. The phosphor bronze was covered by a layer of polyimide with the metal deposited on top. The photolithography pattern used Futurrex NR7-1500PY and had 10 nanometers of chromium and 80 nanometers of gold deposited. We used a bilayer resist system of MircoChem's MMA 8.5 MAA-EL9 Copolymer then 950 PMMA-A4 to develop a large undercut for the electron beam resist. The electron beam lithography pattern had 2 nanometers of chromium and 80 nanometers of gold deposited. The polyimide was etched from underneath the bridge using a reactive ion etch. The bridges averaged 225 nanometers wide, 397 nanometers long, and had an impedance of 81.8 ohms after the reactive ion etch. The break junctions were formed by bending the substrate with fulcrums pushing down at the ends of the 2.5 cm by 1.0 cm wafer and a 250 micrometer pitch screw pushing from the opposite side.

From trial runs so far, we believe we can measure stable impedances of the wires, break them, and reconnect them. Future testing includes breaking the wires in a cooled, vacuum environment.

Integration of Gallium Nitride Nanowires with Silicon Circuits

Lydia Kisley
Chemistry, Wittenberg University

NNIN REU Site: Colorado Nanofabrication Laboratory, University of Colorado at Boulder

NNIN REU Principal Investigator(s): Bart Van Zeghbroeck, Electrical Engineering, University of Colorado at Boulder; Kris Bertness, Optoelectronics Division, National Institute of Standards and Technology

NNIN REU Mentor(s): Chris Dodson, Optoelectronics Division, National Institute of Standards and Technology

Contact: s10.lkisley@wittenberg.edu, bart@colorado.edu, bertness@boulder.nist.gov

Gallium nitride (GaN) nanowires and aluminum and indium GaN alloys have many potential applications when integrated with silicon circuits due to their semiconductor bandgap which ranges from the ultraviolet to infrared areas of the electromagnetic spectrum.

In this study, GaN nanowires synthesized previously through catalyst-free molecular beam epitaxy [1] were integrated with silicon circuits containing p-type metal–oxide–semiconductor field-effect transistors. Basic silicon circuits were designed and fabricated, containing specific contact areas where nanowires could be deposited. GaN nanowires were aligned to the contacts by dielectrophoresis and contacted with an additional metal layer. Previous research has shown GaN nanowires have a good photoconductive response and a high potential for use as ultraviolet photoconductors [2].

Future studies of the integrated GaN nanowires will demonstrate this as one of their potential applications.

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Process Development for a Traveling Wave Terahertz Detector

Benjamin McPheron
Electrical Engineering, Ohio Northern University

NNIN REU Site: Colorado Nanofabrication Laboratory, University of Colorado at Boulder
NNIN REU Principal Investigator(s): Garret Moddel, Electrical Engineering, University of Colorado
NNIN REU Mentor(s): Sachit Grover, Electrical Engineering, University of Colorado
Contact: b-mcpheron.1@onu.edu, moddel@colorado.edu

The terahertz region has been a generally untapped section of the electromagnetic spectrum due to limitations in photonic and classical semiconductor devices. Traditional antenna coupled diode detectors have shown acceptable performance up to 1 THz. It has been proposed to use an antenna coupled traveling-wave diode to achieve high performance in the infrared. These devices channel the radiation received by the antenna into a parallel plate waveguide, which is also the metal-insulator-metal (MIM) diode that rectifies the carrier to produce a signal voltage. This arrangement facilitates a better impedance match between the antenna and the rectifying MIM diode than would a lumped-element diode.

The focus of this project was to develop process steps to fabricate such antennas and MIM waveguides. Basic antenna theory was employed to design broadband antennas suitable for this application. The detectors were designed to receive radiation in the wavelength range of 9 to 12 µm. Electron-beam lithography was extensively used to pattern the sub-micron lithographic dimensions for the waveguide and antennas. Additional steps in the process involved photolithography, reactive-ion etching, and deposition via evaporation and sputtering. Potential applications for these devices include communications and infrared imaging.

Visible Optical Properties of Pulse-Laser-Melted Silicon Implanted with S, Se, Te, B, P and As

Si Hui Athena Pan
Martin A. Fisher School of Physics, Brandeis University

NNIN REU Site: Center for Nanoscale Systems, Harvard University
NNIN REU Principal Investigator(s): Michael Aziz, Engineering and Applied Sciences, Harvard University
NNIN REU Mentor(s): Daniel Recht, School of Engineering and Applied Sciences, Harvard University
Contact: fromaspan@gmail.com, aziz@seas.harvard.edu

The optoelectronic properties of laser-processed, chalcogen-laden silicon in the near infrared region have been well characterized in recent research. In particular, the enhanced sub-band-gap absorption of sulfur-implanted silicon has been used in devices such as IR photodiodes. Meanwhile, the visible spectrum optical properties of silicon supersaturated with chalcogens and other common dopants have not been investigated.

We have developed a procedure to generate a thin film of ion-implanted, laser-melted silicon which allows direct measurement of these materials' transmission spectra in the visible range.

The procedure and present preliminary results are given on the optical properties of silicon implanted with S, Se, Te, B, P and As in various doses.

Fabrication of a Stable Tunable Quantum Hall Interferometer in the Fractional Quantum Hall Regime

Paden Roder
Physics, Grinnell College

NNIN REU Site: Center for Nanoscale Systems, Harvard University
NNIN REU Principal Investigator(s): Charles Marcus, Physics, Harvard University
NNIN REU Mentor(s): Angela Kou, Physics, Harvard University; Doug McClure, Physics, Harvard University
Contact: roderpad@grinnell.edu, marcus@harvard.edu

In the fractional quantum Hall regime at filling factor 5/2, quasiparticles above a ground state of paired composite fermions are predicted to have non-Abelian statistics, which are necessary to implement a topological quantum computer. Observations of non-Abelian statistics at this filling factor require a precise electrostatic tunable electronic Fabry-Perot interferometer on a high mobility GaAs/AlGaAs heterostructure.

The current fabrication of these interference devices have the gates placed on the surface of the chip. Though successful in the integer quantum Hall regime, the devices fail to be stable enough to perform interference measurements in the fractional quantum Hall regime. This is likely due to the fact that the doping of the material is optimized for high mobility, leading to poor gateability.

Here we report on the development of a new generation of devices where etching is used to define the interferometer, allowing the gates to operate at smaller voltages where they are more stable.

Innovative Imprint Lithography for Chip-to-Chip Connections

Laura Gaskins
Chemical Engineering, Rice University

NNIN REU Site: Nanotechnology Research Center, Georgia Institute of Technology
NNIN REU Principal Investigator(s): Paul Kohl, Chemical Engineering, Georgia Institute of Technology
NNIN REU Mentor(s): Venmathy Rajarathinam, Chemical Engineering, Georgia Institute of Technology
Contact: laura.e.gaskins@rice.edu, paul.kohl@chbe.gatech.edu

Transmission lines on circuit boards are currently fabricated simply from copper in a ceramic or glass dielectric, but at longer lengths or higher frequencies this structure proves insufficient to meet the demands of advancing technology. To reduce power loss and increase the speed of signal propagation, an innovative structure is being created that will utilize air as a supreme dielectric in a coaxial system that shields the lines. These measures will reduce noise in the system and increase the maximum distance that the signal can be routed. Furthermore, these results may be achieved without implementing any additional photolithography steps by instead using imprint lithography, chemical-mechanical polishing, and a sacrificial polymer, making the process cost-effective and appealing to industry. Production of these coaxial structures could enable high frequency chip-to-chip signal propagation with low power loss and low manufacturing cost.

Pattern Deposition of Nanoparticles of Different Shapes by Aerosol Route

Richard Frnka
Math/Physics/Computer Science, Eckerd College

NNIN REU Site: Nano Research Facility, Washington University in St. Louis, MO

NNIN REU Principal Investigator & Mentor: Da-Ren Chen, Department of Energy, Environmental, and Chemical Engineering, Washington University in St. Louis

Contact: frnkara@eckerd.edu, chen@wustl.edu

The electrospray system disperses highly-charged, monodisperse droplets to be randomly showered over a large area. By monitoring the flow rate and voltage of the system, nano-sized particles can be distributed over the area. Using the soft lithography technique of micro-contact molding, a certain pattern can be imprinted on a PMMA coated plate. This molding reveals a silver substrate in the pattern that is outlined by the nonconductive polymer. The electrospray apparatus can be used to spray highly positively-charged nanoparticles that are then deposited on the surface in the respective pattern. An electric field is established between spray head and substrate, helping to contain the particles in the given area. Before spraying particles the PMMA surface is charged by depositing a highly conductive solution. The gold nanoparticles used range in size from 10-20 nm and are generally conglomerated inside the desired pattern after spraying.

Being able to control the positioning and patterning of nanoparticles by use of the electospray system will allow a much larger area to be covered in a much shorter time compared to previous deposition experiments.

3D Photonic Crystals Fabricated Through Direct Laser Writing

Meredith Henstridge
Physics, Xavier University

NNIN REU Site: Femtosecond Nanophotonics Lab and Colorado Nanofabrication Lab, University of Colorado at Boulder

NNIN REU Principal Investigator(s): Rafael Piestun, Electrical and Computer Engineering, Physics, University of Colorado at Boulder

NNIN REU Mentor(s): Timothy Gerke, Electrical and Computer Engineering, University of Colorado at Boulder

Contact: henstridgem@xavier.edu, Rafael.Piestun@Colorado.edu

The propagation of light can be controlled in three dimensions by guiding it through a three dimensional photonic crystal. Controlling light in this manner may allow for optical circuitry, the analog to integrated electrical circuitry, to become a reality. Direct laser writing is a form of optical lithography which involves focusing femtosecond laser pulses in order to expose a photoresist substrate in three dimensions. The substrates were prepared in two steps.

First, a three boat thermal evaporator was used to deposit a 50 nm layer of titanium and a 50 nm layer of gold onto a 145 μm thick glass microscope coverslip. The gold layer serves as the seed layer necessary for an electroplating process, and the titanium layer is needed in order for the gold to adhere to the substrate. Next, AZ P4210 photoresist was spin-coated on top of the gold layer. It was determined that 75-100 μW of optical power being scanned through the photoresist at a speed of 25-50 μm/s yielded features on the order of 500 nm. The developed substrates were infiltrated with gold using a standard electroplating process.

The end results were gold photonic crystals with feature sizes down to 500 nm.

Advancing Energy-Efficient Solid State Lighting through Nanotechnology

K. C. Kragh
Engineering Physics, Rose-Hulman Institute of Technology

NNIN REU Site: Penn State Nanofabrication Facility, The Pennsylvania State University

NNIN REU Principal Investigator(s): Dr. Suzanne E. Mohney, Materials Science and Engineering, Penn State University; Co-PI: Dr. Jian Xu, Engineering Science and Mechanics, Penn State University

NNIN REU Mentor(s): Fan Zhang, Engineering Science and Mechanics; Brian Downey, Materials Science and Engineering; Myo Thein, Engineering Science and Mechanics, Penn State University

Contact: kraghkc.at.rose-hulman.edu, mohney.at.ems.psu.edu

As efficient, low power consumption lighting elements, arrays of light emitting diodes could replace traditional incandescent light bulbs in homes and offices. This study examined the feasibility of etching and depositing quantum dots within light emitting diodes to produce white light. Blue wavelength diodes had grooves plasma-etched into the quantum well structure before the addition of yellow quantum dots and evaluation of the resulting illumination. A chlorine and argon based plasma chemistry etched through the gallium nitride based diodes. After addition of the quantum dots, the diodes still demonstrated a characteristic current-voltage curve and a spectrum centered upon the device's wavelength. Beginning to provide a partial white balancing illumination, the complementary colored quantum dots represented a weaker intensity near their characteristic emission wavelength.

Further investigation into etching depth and quantum dot layering could determine the requirements for creating a high-quality white light emitting diode in an efficient process and as an efficient device.

Single Walled Carbon Nanotubes for DNA Translocation

Claire McLellan
Physics, Wake Forest University

NNIN REU Site: ASU NanoFab, Arizona State University
NNIN REU Principal Investigator(s): Stuart Lindsay, Biodesign, Arizona State University
NNIN REU Mentor(s): Jin He, Biodesign, Arizona State University
Contact: mcleca8@wfu.edu, stuart.lindsay@asu.edu

Nanopore deoxyribonucleic acid (DNA) sequencing offers the possibility of rapid single molecule sequencing with long reads, almost no sample preparation, and direct electronic readout from a small, computer-chip-like device. Nanopores are orifices that are so small that electrophoretic translocation of DNA through them necessarily occurs one base at a time.

The focus of this project is to develop a device using single walled carbon nanotube (SWCNTs), as a new type of nanopores to translocate negatively charged DNA through the tubes under electrical fields. The first part of the project was to grow SWCNTs using chemical vapor deposition (CVD) method, characterize SWCNTs using both atomic force microscopy (AFM) and field emission scanning electron microscopy (FESEM), fabricate SWCNT devices using standard microfabrication techniques, and make polydimethylsiloxane (PDMS) microfluidic systems to assemble into SWCNT nanofluidic devices.

For the second half of the project, we analyzed the differences of SWCNTS grown on Si_3N_4 substrates and SiO_2 substrates using SEM and AFM, measured the ionic current of the SWCNT based nanofluidic device, and investigated the translocation of single-stranded DNA through SWCNT by monitoring changes in the ionic current.

Imaging and Characterization of Carbon Nanotube Growth and Transfer

Stephanie Bojarski
Material Science and Engineering, Lehigh University

NNIN REU Site: Stanford Nanofabrication Facility, Stanford University
NNIN REU Principal Investigator(s): Philip Wong, Electrical Engineering, Stanford University
NNIN REU Mentor(s): Arash Hazeghi, Electrical Engineering, Stanford University
Contact: sab410@lehigh.edu, hspwong@stanford.edu

Carbon nanotubes (CNTs) have extremely high strength, flexibility, and excellent electrical properties as either metallic or semiconducting material. Semiconductor CNTs are thus potential candidates for logic devices. Densely packed parallel arrays of CNTs are grown by chemical vapor deposition (CVD) on a quartz wafer and then transferred onto a silicon wafer while, ideally, maintaining the same high density and alignment as the growth. This process must be able to efficiently transfer CNTs to the same area of silicon multiple times, thus yielding an even higher density. However, issues with the current process include incomplete nucleation of CNTs at the catalyst strip along with a low percentage of multiple transferred CNTs.

We use atomic force microscopy (AFM) and scanning electron microscopy (SEM) to measure the approximate diameters and densities of CNTs and nanoparticles present during various stages of the growth and transfer. This helps us to better understand the multiple transfer process by determining how complete the chemical nucleation of CNTs was during the growth and how effective the surface plasma treatment was in eliminating the contamination from the transfer. The optimization of the processes parameters will allow fabrication of devices with high CNT density which is desirable for logic applications.

Horizontally Aligned Carbon Nanotube Composite Beams

Alexander Hryn
Materials Science and Engineering, University of Illinois at Urbana-Champaign

NNIN REU Site: Lurie Nanofabrication Facility, University of Michigan, Ann Arbor
NNIN REU Principal Investigator(s): John Hart, Mechanical Engineering, University of Michigan
NNIN REU Mentor(s): Sameh Tawfick, Mechanical Engineering, Univeristy of Michigan
Contact: ahryn2@illinois.edu, stawfick@umich.edu, ajohnh@umich.edu

Microelectromechanical systems (MEMS) have many applications in a variety of fields from biosensors, to RF filters and transmitters. One of the most important components in a MEMS device and one of the most difficult to manufacture is a cantilever or suspended beam. The cantilever is used as a resonator that, depending on material properties, will respond to or create vibrations only at a specific frequency.

Current MEMS devices make use of beams that are composed of metal, ceramic, aligned carbon nanotubes (CNTs) [1], and CNT composites [2]. Utilizing the high strength per low density of CNTs, composite beams could be made to have higher strengths and resonant frequencies.

As an initial step toward this goal, this project focuses on creating micro-beams of horizontally aligned CNTs (HA-CNTs). This is achieved by growing vertically aligned CNTs and by mechanically rolling them [3] they adhere to the substrate and become horizontally aligned with ~25% packing density. Atomic layer deposition (ALD) of alumina then creates the matrix of the composite. By varying the density HA-CNTs and adjusting the thickness of the ALD coating, we aim to control the modulus and stiffness of the beams, and therefore enable tuning of their resonant frequency. Currently, suspended beams from 5-50 μm have been fabricated and their moduli will be determined.

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Graphene Synthesis on Copper Substrates using Chemical Vapor Deposition

Mark Borysiak
Chemical Engineering, Ohio State University

NNIN REU Site: Microelectronics Research Center, The University of Texas at Austin

NNIN REU Principal Investigator(s): Professor Rodney Ruoff, Department of Mechanical Engineering and Texas Materials Institute, University of Texas

NNIN REU Mentor(s): Xuesong Li, Department of Mechanical Engineering, University of Texas

Contact: borysiak.1@osu.edu, r.ruoff@mail.utexas.edu

Graphene is an extremely interesting and potentially important material with unique and desirable physical characteristics. There are many possible practical applications envisioned for graphene, but large scale, high-quality graphene is needed to achieve these uses in many cases. The research presented focuses on monolayer graphene synthesis on 25-μm thick Cu substrates, which allows for growth on the scale of a few inches, while also showing to be predominantly uniform monolayer graphene. The graphene was grown using chemical vapor deposition (CVD) with methane and hydrogen gas in a tube furnace vacuum system. The as-grown graphene was characterized using a scanning electron microscope to understand growth at different conditions to find desired growth parameters, while also confirming it to be mostly uniform monolayer graphene. The graphene films were then transferred to SiO_2/Si wafers for further characterization by optical microscopy and micro Raman spectroscopy.

To date we have seen that higher temperature growth of the graphene, in general, results in higher quality graphene sheets, depending on the growth time and quality of the Cu substrates.

Atomic Layer Deposition on Surfaces Modified by Thin Interfacial Organic Layers

Scott Isaacson
Chemical Engineering, University of Minnesota

NNIN REU Site: Cornell NanoScale Science & Technology Facility, Cornell University
NNIN REU Principal Investigator(s): James R. Engstrom, Chemical and Biomolecular Engr, Cornell University
NNIN REU Mentor(s): Kevin J. Hughes, Chemical and Biomolecular Engineering, Cornell University
Contact: isaac145@umn.edu, jre7@cornell.edu

Atomic layer deposition (ALD) of aluminum oxide, Al_2O_3, has been performed on bare silicon dioxide and a porous low-κ SiO_2-based dielectric, and on both of these substrates after modification with thin interfacial organic layers. The Al_2O_3 films have been characterized using ellipsometry, atomic force microscopy (AFM), and x-ray photoelectron spectroscopy (XPS).

The objective of this study is to determine how the structure and reactivity of the organic layer affects the growth rate and morphology of the deposited Al_2O_3 film.

We find that Al_2O_3 films grown on silicon dioxide modified with a nitrogen-containing organic layer or polyethylene glycol grow at a rate of approximately 1 Å per cycle, equal to the deposition rate of Al_2O_3 on bare silicon dioxide, while a fluorinated hydrocarbon SAM strongly attenuates the rate of growth in the initial ~ 15 cycles.

Study of these films by AFM shows a surface roughness of less than 0.5 nm, and XPS analysis confirms the presence of the organic layer at the Al_2O_3/substrate interface after ALD.

Magnetron Sputtering and Characterization of Ag-Si for Infrared Photodetectors

John Abrahams
Electrical Engineering and Physics, University of Maryland at College Park

NNIN REU Site: Howard Nanoscale Science and Engineering Facility (HNF), Howard University
NNIN REU Principal Investigator(s): Dr. Clayton Bates, Electrical Engineering, Howard University
NNIN REU Mentor(s): Dr. Chichang Zhang, Electrical Engineering, Howard University
Contact: jabrah23@umd.edu, bates@msrce.howard.edu

Silver-silicon (Ag-Si) composite films are the first metal-semiconductor composite system to demonstrate a response to radiation over the 1-14 μm wavelength range from liquid nitrogen to room temperature. Magnetron co-sputtering at 550°C was used to deposit 1 μm thick Ag/n-Si films with Ag concentrations ranging from 13% and 23% onto highly resistive n-Si (111) substrates. The Van der Pauw method was used to characterize the transport properties of these films. Room temperature resistivity measurements on the order of 10^{-1} Ω•cm are higher than expected of only highly doped n-Si. Lower resistivity was recorded with higher Ag concentration. Measured mobility of around 1 $cm^2/V \cdot s$ was observed at room temperature. This low mobility is due to the high dopant concentration in the silicon. Resistivity and mobility measurements are different from values of only highly doped n-Si. Carrier concentration at room temperature is consistent with highly doped n-Si for lower Ag concentration, but generally increased with Ag concentration.

While the behavior of carrier concentration is not currently fully understood for Ag/n-Si systems, the above results were verified at the National Institute of Standards and Technology in Gaithersburg, MD.

Materials for CZTS Photovoltaic Devices

Rachel Hoffman
Chemical Engineering, Cornell University

NNIN REU Site: Minnesota Nanotechnology Cluster, University of Minnesota-Twin Cities

NNIN REU Principal Investigator(s): Stephen Campbell, Electrical Engineering, University of Minnesota; Eray Aydil, Chemical Engineering and Materials Science, University of Minnesota

NNIN REU Mentor(s): Kushagra Nagaich, Electrical Engineering, University of Minnesota; Banu Selin Tosun, Chemical Engineering and Materials Science, University of Minnesota

Contact: rsh95@cornell.edu, campb001@umn.edu

Copper zinc tin sulfide (Cu_2ZnSnS_4 or CZTS) is a promising thin film solar cell material. It is modeled after copper indium gallium selenide (CIGS), but unlike CIGS, CZTS is composed of nontoxic, abundant materials. Toxic CdS is typically used with CIGS to complete the *pn* heterojunction.

In the first half of this project, chemical bath deposition of ZnS was explored as a replacement for CdS. The deposition of CdZnS, which has a more favorable band gap with CIGS, was also investigated. ZnS deposition on glass slides looks promising and merits further investigation. CdZnS deposition on molybdenum coated glass slides was unsuccessful as XRD revealed no Zn was present in the film.

The second part of this project dealt with the characterization of CZTS thin films as related to solar cell properties. To make the CZTS films zinc, copper, and tin were deposited on molybdenum coated quartz slides using thermal evaporation, and then annealed with sulfur in a furnace. Films were characterized using XRD. Solar cells are being made by depositing CdS using chemical bath deposition followed by sputtering aluminum doped zinc oxide. Solar cells properties will then be measured.

Space-Charge Limited Current Calculations in Nanowires

Ian Braly
Chemical Engineering, Oregon State University

NNIN REU Site: Center for Nanotechnology, University of Washington, Seattle
NNIN REU Principal Investigator(s): Dr. David Ginger, Chemistry, University of Washington
NNIN REU Mentor(s): Obadiah Reid, Chemistry, University of Washington
Contact: bralyi@onid.orst.edu, ginger@chem.washington.edu

Semi-conductive nanowires are being used in organic solar-cells to supply the active layer with an effective hole-transport network while controlling bulk-heterojunction morphology. Conductive-atomic force microscopy (c-AFM) can be used to make charge carrier mobility measurements with nanoscale resolution using the space-charge limited current (SCLC) method. Nano-wires made from the semiconducting polymer polybutylthiophene (P3BT) have been characterized with this method, but the results do not agree with existing computational models. Our hypothesis is that this lack of concurrence is due to a difference in geometry between the existing models and the c-AFM SCLC experiments on these polymer nanowires.

To test this hypothesis we have created a numerical model of the c-AFM experiment that includes a small circular injection surface to simulate the contact point of the AFM tip, and the local dielectric environment of the nanowire. We use calculations on a well understood geometry (plane-plane and point-point electrodes) as a control, and examine how known scaling relationships between current density and various parameters change with the geometry. These include: (a) injecting surface charge carrier density; (b) injecting surface voltage; and (c) transport distance.

We compare these new scaling relationships from the calculations with our experimental results.

Cyclic Charging of Reduction-Oxidation (redox) Markers in Metal-Oxide-Semiconductor Capacitors

Julie Bellfy
Chemical Engineering, Villanova University

NNIN REU Site: Cornell NanoScale Science & Technology Facility, Cornell University
NNIN REU Principal Investigator(s): Edwin Kan, Electrical and Computer Engineering, Cornell University
NNIN REU Mentor(s): Jonathan Shaw, Electrical and Computer Engineering, Cornell University
Contact: Julie.Bellfy@villanova.edu, kan@ece.cornell.edu

The cyclic charging of Reduction-Oxidation (redox) markers in metal-oxide-semiconductor (MOS) capacitors would allow for the creation of a nonvolatile memory. In a MOS capacitor, the accumulation of negative charge on the gate metal attracts positively charged carriers or holes to the oxide-semiconductor interface. As the applied voltage increases, these holes are forced into the substrate and the redox molecules. The holes will move the redox molecules between their naturally occurring discrete energy levels and store a charge. This stored charge would allow for the creation of memory. This memory would be able to function at low potentials.

The first part of this project was to determine if the molecules could actually store the desired charge. Then different methods for the deposition of the control oxide were used. Currently there are adjustment being made to determine the best ratio between redox molecules and solvent molecules.

Ohmic Contact Study for Gallium Nitride-Based High Electron Mobility Transistors and Ultra-Short N-Type THz Devices

Ian Walsh
Applied Physics, Rice University

NNIN REU Site: Cornell NanoScale Science & Technology Facility, Cornell University

NNIN REU Principal Investigator(s): Professor Lester F. Eastman, Electrical and Computer Engineering, Cornell University

NNIN REU Mentor(s): Quentin Diduck, Electrical and Computer Engineering, Cornell University; Jonathan Felbinger, Electrical and Computer Engineering, Cornell University

Contact: iaw1@rice.edu, jgf27@cornell.edu

Gallium nitride (GaN) based high electron mobility transistors (HEMTs) and terahertz (THz) emission devices are promising technologies for enabling high speed, high power applications. The formation of reliable, low resistance, thermally stable ohmic contacts is a crucial part of improving device performance.

In this study, we examine various novel metal stacks for both HEMT and THz type substrates in the goal of achieving lower transfer resistance and improved repeatability. We use rapid thermal annealing (RTA) to study the stacks' sensitivity to anneal time and temperature, and the transfer resistance measurements are performed using the transfer length method (TLM).

At the time of this writing, consistent results for HEMTs of R_t as low as 0.3 ohm-mm ($R_{sc} \approx 6 \times 10^{-8}$ ohm-cm^2) have been achieved with metal stacks utilizing vanadium (V) as the first deposited metal layer. For the THz substrate, stacks using niobium (Nb) in the first layer have exhibited R_t of 0.12 ohm-mm ($R_{sc} \approx 1.3 \times 10^{-7}$ ohm-cm^2) before annealing.

Magneto-Transport in Photoexcited Diamond

Sarah Reiff
Physics, Marquette University

NNIN REU Site: Nanotech @ UCSB, University of California Santa Barbara

NNIN REU Principal Investigator(s): David Awschalom, Center for Spintronics and Quantum Computation, University of California Santa Barbara

NNIN REU Mentor(s): Joseph Heremans (2005 NNIN REU at Cornell), Center for Spintronics and Quantum Computation, University of California Santa Barbara

Contact: sarah.reiff@marquette.edu, awsch@physics.ucsb.edu

Diamond's superior physical properties, including high thermal conductivity, ultrahardness, and a large bandgap, make it a useful material for electronic and spintronic device applications. However, for diamond to be a viable alternative to present materials, certain electronic properties need to be explored further. Nitrogen-rich diamond (type Ib) have shown photo-induced charge storage effects likely due to the presence of substitutional nitrogen defects [1].

Here we present photoexcited Hall effect measurements of single-crystal, nitrogen-rich diamond (type Ib) with Ti/Pt/Au gates in Van der Pauw geometry. These measurements were taken using a physical property measurement system (PPMS). A fiber-coupled 532 nm laser was directed into the PPMS through specialized fitting [2], with the other end pigtailed directly onto the sample [3]. The sample and optical fiber assembly was inserted into the PPMS using a custom designed probe insert. The carrier type and density were determined using these Hall effect measurements.

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III-V MOSFET Fabrication

Lorraine Weis
Engineering Physics, Franklin W. Olin College of Engineering

NNIN REU Site: Nanotech @ UCSB, University of California Santa Barbara
NNIN REU Principal Investigator(s): Mark Rodwell, Electrical and Computer Engineering, UCSB
NNIN REU Mentor(s): Gregory Burek, Electrical and Computer Engineering, UCSB
Contact: lorraine.weis@students.olin.edu, rodwell@ece.ucsb.edu

Scalable transistor technology is necessary for higher frequency electronics, as well as cheaper, more energy efficient devices. While silicon technology may be reaching its limits, new materials are being developed for use in complementary metal-oxide semiconductor (CMOS) transistors below the sub-22 nm technology node. However, as gate lengths decrease, other features need to scale as well.

Sidewalls, also called spacers, insulate the drain and source metal contacts from the gate of the transistor. Two techniques were compared for producing thin, reliable sidewalls: over-etching of 30 nm sidewalls and slow deposition of thinner sidewalls. The sidewalls of varying thickness were then electrically tested for their effectiveness as insulators.

This project will thus find the optimal sidewall process for use in metal-oxide semiconductor field effect transistors (MOSFETs).

Materials Studies on $La_{0.6}Sr_{0.4}Co_{0.8}Fe_{0.2}O_{3-\delta}$ Cathodes for Solid Oxide Fuel Cells

Tyler Cain
Materials Science and Engineering, University of Illinois at Urbana-Champaign

NNIN REU Site: Center for Nanoscale Systems, Harvard University

NNIN REU Principal Investigator(s): Shriram Ramanathan, School of Engineering and Applied Science, Harvard University

NNIN REU Mentor(s): Bo-Kuai Lai, School of Engineering and Applied Science, Harvard University

Contact: tcain2@illinois.edu, shriram@seas.harvard.edu

Solid oxide fuel cells (SOFCs) are attractive electrical power devices because of their energy conversion efficiency, low emissions, and flexibility of fuel sources. The materials used in these devices determine their cost, performance, and reliability. $La_{0.6}Sr_{0.4}Co_{0.8}Fe_{0.2}O_{3-\delta}$ (LSCF) has been explored as a cathode material for SOFCs.

We have studied the materials properties of RF-sputtered LSCF thin films on yttria-stabilized zirconia electrolytes. This project aims to understand the effect of oxygen deficiency in LSCF thin films. Specifically, we compare resistivity, x-ray diffraction, density, film stress, and grain size in films of differing oxygen concentration. Understanding these effects of oxygen deficiency in LSCF thin films has influence on SOFC processing conditions and device operation.

Metallization for High Temperature Electronics

K. C. Kragh
Engineering Physics, Rose-Hulman Institute of Technology

NNIN REU Site: Penn State Nanofabrication Facility, The Pennsylvania State University

NNIN REU Principal Investigator(s): Dr. Suzanne E. Mohney, Materials Science and Engineering, The Pennsylvania State University

NNIN REU Mentor(s): Brian Downey, Materials Science and Engineering, Penn State University

Contact: kraghkc@rose-hulman.edu, mohney@ems.psu.edu

With its wide band gap and large capacity for current and power, silicon carbide can replace silicon as the semiconductor for high temperature and high power electronics. This study investigated metallic capping materials that could withstand elevated temperatures, while maintaining a low sheet resistance.

Sputtered gold-ruthenium films were monitored for agglomeration through microscopy and for sheet resistance through the van der Pauw technique. Low resistance pure gold films demonstrated significant agglomeration upon annealing at 600°C. Ruthenium was utilized in alloys to stabilize the gold films with limited increase in resistance. Co-sputtered gold and ruthenium films underwent agglomeration and an increase in sheet resistance after prolonged annealing. Pure ruthenium, however, withstood agglomeration through fifty hours of annealing while sustaining an acceptably low sheet resistance. Ruthenium also demonstrated better adhesion than gold-based films. Despite the popularity of gold, a capping layer of 150 nm of ruthenium provides high-quality adhesion and low resistance through continued annealing at 600°C.

Fracture at the Nanoscale

Denys Zhuo
Department of Material Science and Engineering,
Massachusetts Institute of Technology

NNIN REU Site: Penn State Nanofabrication Facility, The Pennsylvania State University

NNIN REU Principal Investigator(s): Dr. Aman Haque, Department of Mechanical and Nuclear Engineering, Pennsylvania State University

NNIN REU Mentor(s): Sandeep Kumar, Department of Mechanical and Nuclear Engineering, Pennsylvania State University

Contact: dzhuo@mit.edu, mah37@engr.psu.edu

The objective of this research is to develop a micro-electro-mechanical systems (MEMS)-based tensile and fracture testing device for ultra thin specimens *in-situ* in the transmission electron microscope (TEM). In particular, we used nanofabrication and innovative design principles to miniaturize a mechanical testing device to 3x5 mm size.

The technical contribution of this research is a unique experimental technique that can perform tensile/fracture testing of nanoscale materials with virtually no restriction on specimen thickness/size. The scientific contribution of this research is that the fundamentals of fracture at extreme (1-10 nm) length-scales will be explored, both qualitatively and quantitatively.

Using this technique, the mechanics of fracture in 3-5 nm thick freestanding glassy carbon specimens can be studied. Glassy carbon is an attractive specimen material because it allows accurate control of sample thicknesses at the 1-10 nm length-scale. This material is chosen for its exciting applications as a molecular sieve or as a catalyst for gas separation. Tensile testing devices and the ultra thin glassy carbon samples specimens were designed and fabricated then integrated together.

The next step is testing of the specimens inside TEM at magnifications of 150,000-200,000x in order to understand how the material fails at very small scales.

Large-Scale Chemical Vapor Deposition Growth of Graphene over Thin Films of Cobalt

Devanand Sukhdeo
Electrical Engineering, Columbia University

NNIN REU Site: Microelectronics Research Center, The University of Texas at Austin

NNIN REU Principal Investigator(s): Dr. Sanjay Banerjee, Electrical Engineering, The University of Texas at Austin

NNIN REU Mentor(s): Shagandeep Kaur, Electrical Engineering, The University of Texas at Austin

Contact: dss2129@columbia.edu, banerjee@ece.utexas.edu

The synthesis of graphene was demonstrated by chemical vapor deposition, using methane as a precursor, over thin films of cobalt. At sufficiently high temperatures, carbon from the methane precursor dissolved in the cobalt film. As the cobalt cooled to room temperature, its solubility decreased, thereby causing the dissolved carbon to segregate to the surface in the form of graphene. Subsequently etching away the underlying cobalt made it possible to transfer the graphene film to arbitrary substrates, including insulator substrates such as silicon dioxide. Once transferred to a silicon dioxide substrate, further analysis of the graphene films revealed that they generally consisted of a large contiguous region of thin few-layer graphene, with many patches of thicker multi-layer graphene present throughout the film.

Nanotextured Surfaces: New Generation Bioelectronic Interfaces for Nanomedicine

Ericka Cottman
Electrical Engineering, Virginia Commonwealth University

NNIN REU Site: ASU NanoFab, Arizona State University

NNIN REU Principal Investigator(s): Dr. Jennifer Blain-Christen, Electrical Engineering, Arizona State University

NNIN REU Mentor(s): David Welch, BioEngineering, Arizona State University

Contact: ecottman@asu.edu and jblainch@asu.edu

Bioelectronics is a field of study that contributes to a growing intersection between nanostructures and nanomedicine. One application is using nanostructures for interfacing cells. This can help improve standard signal measurements from cells on a two-dimensional electrode array by using a nanotextured electrode surface instead. Nanotexturing increases the surface area to improve the adhesion of cells to electrodes and provides a more efficient electrical interface. We used a porous alumina membrane as a template to provide uniform nano-scale pores for electrodeposition of gold. Electrodeposition is an electrochemical method for driving gold cations toward an electrode in solution. These cations precipitate onto the cathode filling the pores to create free-standing gold rods.

We fabricated two-dimensional arrays of gold electrodes using standard lithography and lift-off techniques. In addition, we performed extensive characterization of electrodeposition parameters including, current density, deposition rate, nanorod uniformity, and experimental repeatability. Finally, we cultured HL-1 cardiomyocytes on the nanotextured gold arrays and characterized morphology, adhesion, and proliferation rate.

Nanoporous Surfaces: Bioelectric Interfaces for Pathogen Detection

Lilian Gong
Department of Biological Chemistry, Wellesley College

NNIN REU Site: ASU NanoFab, Arizona State University

NNIN REU Principal Investigator(s): Shalini Prasad; Electrical, Computer, and Energy Engineering, Arizona State University

NNIN REU Mentor(s): Gaurav Chatterjee, Srivatsa Aithal; Electrical, Computer, and Energy Engineering, Arizona State University

Contact: lgong@wellesley.edu, Gaurav.Chatterjee@asu.edu, Shalini.Prasad.1@asu.edu

The goal of this project is to build a biosensor to detect low concentrations of pathogens. Purity of a liquid depends on the pathogens that constitute it. We used a label free technique, which uses electrochemical impedance spectroscopy (EIS) for detecting pathogens. By keeping our methods label free, detecting pathogens is cheaper and less time consuming, as compared to conventional methods.

We used a printed circuit board (PCB) based-device and an alumina membrane to generate a nanoporous surface. The alumina membrane has pores with a diameter of the order of tens of nanometers. By overlaying the membrane on top of the interdigitated electrodes of the PCB, a high-density array of nanowells is formed, which facilitates nano-confinement and allows for size based trapping of the pathogens.

We used layer-by-layer chemistry. The membrane was functionalized such that the cationic polymer attaches to the membrane. The endotoxin, being anionic, binds to the cationic polymer, forming an electrical double layer. The variations in the impedance of the electrical double layer due to the changes in the concentrations of the pathogen were characterized using EIS.

We have identified the performance parameters of the biosensor for pathogen detection.

Optical Detection of Thrombosis Formation within a Microfluidic Device using a Helium-Neon Laser as a Radiation Source

Adam Kozak
Biomedical Engineering, University of Rochester

NNIN REU Site: Nanotechnology Research Center, Georgia Institute of Technology

NNIN REU Principal Investigator(s): Craig Forest, Assistant Professor of Mechanical Engineering, Georgia Tech

NNIN REU Mentor(s): Melissa Li, Biomedical Engineering, Georgia Institute of Technology

Contact: akozak2@gmail.com, cforest@gatech.edu

Understanding the dynamics of blood clotting is critically important to clinical evaluations of patients and to research laboratories studying diseases and drug effects. Particularly, the necessary conditions for acute thrombus formation are not well understood, and instrumentation has been limited in this context. The emerging field of microfluidics has led to significant advances in examining thrombus formation *in vitro*, allowing biologically relevant geometries and the measurement of occlusion in real time. However, current techniques (antibody binding, microscopic imaging) produce data with insufficient time and spatial resolution, vital parameters in measuring volumetric thrombus growth.

We present a method of detecting thrombus formation and time-to-occlusion within a microfluidic device utilizing a helium-neon laser, taking advantage of the low absorbance of platelets relative to erythrocytes. This is method provides higher time resolution, smaller footprint, and larger signal-to-noise ratio compared to existing art. Our method is also capable of measuring the hematocrit of the blood, since this parameter has been shown to affect thrombus growth in the past.

Current progress is attempting to implement this method in a high-throughput device capable of measuring the occlusion rates of four separate channels of varying shear rate.

Development of a Multiplex CARS Flow Cytometer for Label-Free, Real-Time Classification

Hamsa Sridhar
Physics and Mathematics, Harvard University

NNIN REU Site: Nanotechnology Research Center, Georgia Institute of Technology

NNIN REU Principal Investigator(s): Ali Adibi, Electrical and Computer Engineering, Georgia Tech

NNIN REU Mentor(s): Siva Yegnanarayanan and Charles Camp, Electrical and Computer Engineering, Georgia Institute of Technology

Contact: hsridhar@fas.harvard.edu, adibi@ece.gatech.edu

Multiplex coherent anti-Stokes Raman scattering (MCARS) is a label-free method of optical imaging that uses the vibrational chemical signature of molecules to uniquely identify and visualize them. As a result, it eliminates the need for fluorophores, which can disrupt the physiological processes of living samples. Moreover, the coherent pumping of Raman bands and multiplex detection allow for high sensitivity and full spectrum measurements.

In this work, MCARS was applied to cytometric analysis on a microfluidic chip. This new addition to flow cytometry complements traditional sizing and morphological information with fluorophore-free chemical information. The aim is to fabricate a MCARS cytometer that can effectively flow a mixture of various cells in a stream of fluid and analyze their chemical signatures in real-time, thereby allowing for down-stream sorting of the sample.

First, microfluidic channels of various sizes and geometries were designed in AutoCAD and fabricated using photolithography. Fluid flows through such geometries were modeled theoretically using COMSOL Multiphysics to determine optimal flow rates and particle sorting methods. Additionally, a program was written in MATLAB for real-time analysis of MCARS spectral data using principal component analysis. As proof of principle, chemically specific differentiation of polystyrene and PMMS microbeads was experimentally demonstrated.

Using Molecular Self-Assembly for Surface Charged Monolayers to Control Bio-Assembly

Theresia Monikang
Chemistry, Hampton University

NNIN REU Site: Howard Nanoscale Science and Engineering Facility (HNF), Howard University
NNIN REU Principal Investigator(s): Dr. James Mitchell, Chemistry, Howard University
NNIN REU Mentor(s): Dr. Tina Brower Thomas, Chemistry, Howard University
Contact: theraneh@yahoo.com, chemdance@yahoo.com

Self assembled biological molecules are being utilized in many ways to include forming hydrogel networks and nanoscale tubles. The goal of the project is to develop a method to preferential assemble biomaterials on surfaces using ionic interactions.

We employ photolithography to prepare a simple pattern—an array of Au(III) on mica. We form a monolayer of aromatic thiol on the Au (III) surface. The monolayer is then treated with a photoresist followed by selective exposure leaving part of the monolayer inaccessible to a solution of mercury (II) perchlorate hydrate. The mercury (II) perchlorate provides a positive charge to selective areas of the pattern surface. Finally the array is introduced to various biomaterials with the expectation that localized ionic interactions will result in preferential assembly of the biomaterial. The array is examined by Kelvin force microscopy (KFM) before and after their introduction to biomaterial.

Development and Fabrication of a Micro-Microbial Fuel Cell (µMFC)

Isaac Markus
Chemical Engineering, The Cooper Union

NNIN REU Site: Cornell NanoScale Science & Technology Facility, Cornell University

NNIN REU Principal Investigator(s): Largus T. Angenent, Department of Biological and Environmental Engineering, Cornell University

NNIN REU Mentor(s): Arvind Venkataraman, Department of Biological and Environmental Engineering, Cornell University

Contact: markus@cooper.edu, la249@cornell.edu

Bioelectrochemical systems (BESs) are being widely proposed for wastewater treatment, chemical production, hydrogen generation and biosensors. One example of a BES is a microbial fuel cell (MFC) in which anaerobic bacteria oxidize carbon sources, such as glucose and acetate, in the anode to generate an electric current.

Here, we developed and fabricated a micro-microbial fuel cell (μMFC) with channel dimensions of 100 μm x 100 μm. First, a silicon (Si) master was fabricated using standard photolithography techniques and plasma etching. Second, a gold/titanium (Au/Ti) electrode architecture was cast using standard liftoff processes on borofloat wafers. Third, the channels for the μMFC were cast using a mixture of polydimethylsiloxane (PDMS) and zirconium oxide. The latter chemical addition renders the polymeric structure as a proton exchange membrane (PEM) [1].

This μMFC will be operated with *Shewanella oneidensis* MR-I under anaerobic conditions to obtain electrochemical data and real time microscopy images.

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Development of an Intravessel Xylem Probe for Viniculture and Forest Ecology

Ellen Sedlack
Microelectronic Engineering, Rochester Institute of Technology

NNIN REU Site: Cornell NanoScale Science & Technology Facility, Cornell University
NNIN REU Principal Investigator(s): Abraham Stroock, Chemical and Biomolecular Engr, Cornell University
NNIN REU Mentor(s): Amit Pharkya, Chemical and Biomolecular Engineering, Cornell University
Contact: exs2093@rit.edu, ads10@cornell.edu

Modern botanical research has demanded better, more accurate and real-time technology to measure water transport in the xylem tissues of plants. The purpose of this project was to develop an intravessel xylem probe at the micro scale. Direct xylem probing promises to monitor instantaneous plant metabolism.

Plant fluids defy sampling as they operate at a high negative pressure, thus making the sap metastable. Conventional xylem probes have proven less effective due to their large size, restricted function range and poor sealing capabilities to plant tissues. A sufficiently-small sized probe promises to surpass such problems.

After photolithographic masking, microneedles of varying dimensions were etched into a silicon substrate. The key fabrication challenges are bore loss due to high aspect ratios and needle fracture. The smallest needles featured a 20 μm inner diameter, a 30 μm outer diameter and a 250 μm length. Various needle sizes have been etched and readied for testing. A successful needle will be sufficiently robust to penetrate the xylem without buckling and will have a bore that is sized to avoid clogging. After successful leaf-application, a water flow monitoring pressure sensor will be integrated with the microneedle to form a microelectromechanical systems (MEMs) device.

Microfluidic Single Cell Assay Chip for Cancer Efficacy Tests

Nicolas Andrew Shillingford-Cordero
Microbiology, Cornell University

NNIN REU Site: Lurie Nanofabrication Facility, University of Michigan, Ann Arbor

NNIN REU Principal Investigator(s): Euisik Yoon, Electrical Engineering, University of Michigan

NNIN REU Mentor(s): Xia Lou, Electrical Engineering, University of Michigan

Contact: nac56@cornell.edu, esyoon@umich.edu

Single-cell resolution assays incomparably increase the power of drug screens over conventional colorimetric assays by providing quantitative data. Cell-to-cell interactions present in traditional bulk sampling procedures can mask nuances where individual cells are concerned, causing rich amounts of information to be overlooked. Advances in microfluidic technology have allowed high throughput single-cell drug screens to be performed while exercising precise control over cell loading and culturing conditions.

This project focused on optimizing the design and operation of one of these microfluidic single-cell drug screening platforms. Photolithography of SU-8, a negative photoresist, was used to create the microfluidic chip features on a silicon wafer, which then functioned as a mold in PDMS chip fabrication. GFP stained glioblastoma multiforme cells were then introduced to the devices and, upon their capture within individual microwells, cultured to the neurosphere stage while being subjected to drug screens alongside control groups.

Statistics can be obtained for quantitative cell viability data when there are sufficient single-cell samples in the microfluidic chip (more than 100) that have been maintained for more than seven days.

Nanostructured Scaffolds for Tissue Engineering Applications

Nathaniel Hogrebe
Chemical Engineering, University of Dayton

NNIN REU Site: Nano Research Facility, Washington University in St. Louis, MO
NNIN REU Principal Investigator(s): Younan Xia, Biomedical Engineering, Washington University in St. Louis
NNIN REU Mentor(s): Jingwei Xie, Biomedical Engineering, Washington University in St. Louis
Contact: hogrebnj@notes.udayton.edu, xia@biomed.wustl.edu

Nanofibers fabricated through the process of electrospinning the synthetic biodegradable polymer poly(lactic-co-glycolic acid), or PLGA, offer a promising prospect for the extracellular scaffold necessary in repairing damaged tissue as a result of their high porosity and large surface area. By depositing a gradient coating of the bone mineral hydroxyapatite onto the nanofibers, cell attachment and differentiation can be altered along the length of the scaffold. This characteristic is especially desirable for the interface between tendon and bone, which is a site of much localized stress as a result of the non-uniform tissue composition as it changes from soft tendon to hard bone.

The objectives of this project, therefore, were to fabricate PLGA nanofiber scaffolds with both random and aligned orientations of the fibers, deposit hydroxyapatite onto the surface of the scaffolds in a gradient-like fashion, culture the bone mesenchymal stem cells of rats onto these scaffolds, and finally characterize the cell activity in response to both varying hydroxyapatite concentration and nanofiber orientation in an effort to determine if these biomineralized scaffolds would be useful in the regeneration of damaged tendon-to-bone attachment sites.

All sample scaffolds have been successfully fabricated and characterized and are currently undergoing the cell culturing process.

Antimicrobial Effects of Metal Oxide Nanoparticles

Angela K. Horst
Biochemistry, Clarke College

NNIN REU Site: Nano Research Facility, Washington University in St. Louis, MO

NNIN REU Principal Investigator(s): Dr. Yinjie Tang, Department of Environmental and Chemical Engineering, Washington University in Saint Louis

NNIN REU Mentor(s): Dr. Bing Wu, Department of Environmental and Chemical Engineering, Washington University in Saint Louis

Contact: angela.horst@clarke.edu, yinjie.tang@seas.wustl.edu

In a world of emerging nanotechnology, one of the primary concerns is the potential environmental impact of nanoparticles (NPs). An efficient way to estimate nanotoxicity is to monitor the response of bacteria exposed to these particles. This experiment explored the antimicrobial properties of six metal oxide NPs against *Escherichia coli*. The toxicity of these NPs was tested using three methods: measuring protein efficiency in the presence of NPs, culturing in liquid media containing NPs, and electrospraying the NPs on a biofilm of bacteria. In an aqueous environment, protein function (here, glycolytic enzymes) were unaffected. Also, there was noticeable aggregation, preventing effective interaction between the particles and the bacteria; therefore the limited growth inhibition observed for all metal oxide NPs was attributed to their ionic species. On the other hand, the electrospray technique allowed direct interaction between the NPs and cells, which resulted in a higher death rate when exposed to oxidized nickel, zinc, and cobalt species; but a decrease in the antimicrobial properties of oxidized copper.

The disparity in the results of the two exposure techniques indicates that the exposure method of NPs effect nanotoxicity.

Microfabrication of Heaters and Resistance Thermal Detectors for Simulation of Hotspots

Julia Sokol
Mechanical Engineering, Harvard University

NNIN REU Site: Nanotechnology Research Center, Georgia Institute of Technology
NNIN REU Principal Investigator(s): Dr. Andrei Fedorov, Mechanical Engineering, Georgia Tech
NNIN REU Mentor(s): Shankar Narayanan, Mechanical Engineering, Georgia Institute of Technology
Contact: jsokol@fas.harvard.edu, andrei.fedorov@me.gatech.edu, shankar.narayanan@gatech.edu

The continuous development of microprocessors to enhance performance has resulted in increasing power density and decreasing feature sizes. Consequently, it has become challenging to provide sufficient cooling for microprocessors requiring more effective cooling mechanisms than the often-used heat sinks or fans. Furthermore, non-uniform power densities in microprocessors have resulted in the development of hotspots with higher heat generation, as opposed to spatially-uniform heating across the whole surface, calling for localized cooling solutions. In order to dissipate high heat fluxes, phase change cooling is more effective than single phase convection due to the advantage offered by significant latent heat of vaporization of liquids.

This project is concerned with the development of a cooling system (called Nanopatch) for hot spots capable of dissipating high heat fluxes using evaporation of a thin liquid film. Specifically, devices consisting of a heater and sensor system were fabricated to test the operation of the Nanopatch. Each device consists of a central hotspot heater surrounded by multiple sensors fabricated on a Pyrex® substrate using metal deposition and lift-off techniques.

The sensors surrounding the central heater are resistance temperature detectors that will be used to provide an accurate thermal map of the substrate while the central heater is activated. Thus, this device will be capable of providing temperature measurements that will allow to correctly distinguish between the amount of heat dissipated by the cooling patch versus heat lost to the substrate and the ambient.

Fabrication and Design of Nanowire Transistors

Gabrielle Castillo
Materials Science & Engineering, Arizona State University

NNIN REU Site: Howard Nanoscale Science and Engineering Facility (HNF), Howard University
NNIN REU Principal Investigator(s): Dr. Gary L. Harris, HNF, Howard University, Washington, DC
NNIN REU Mentor(s): Dr. William Rose, HNF, Howard University, Washington DC
Contact: keroppiqueen8@yahoo.com; gharris@msrce.howard.edu

The semiconductor industry has constantly trended towards smaller, faster, and energy saving electronics. This has both driven down the size of the individual device and subsequently increased the number of devices on a single chip. However, the current technology demonstrated by complementary metal-oxide semiconductor devices is reaching its operational limits and has now led scientists to rigorously explore the realm of nanotechnology as the new frontier for electronic devices.

The aim of this project is to fabricate nano field effect transistors (nano FETs) using nanowires. Beginning with a p-type Si substrate with a $\rho < 0.6\ \Omega$-cm, a SiO_2 layer about 70 nm thick is formed using thermal oxidation. An ohmic contact is thermally evaporated onto the backside of the silicon using a silicon-aluminum eutectic solution annealed at 500°C. This device structure allows the current-voltage curve to appear symmetric. An appropriate mask is designed with 20,000 nm spacing between each electrode. The purpose of the design is to successfully land a nanowire between two contacts. E-beam lithography is then used to complete the connection. These nanoFET devices are characterized using their current-voltage curves.

This research is supported by the National Science Foundation through the National Nanotechnology Infrastructure Network Research Experience for Undergraduates (NNIN REU) Program.

Fabrication, Characterization and Modeling of a Novel Optofluidic Biosensor

Michael Zakrewsky
Chemical Engineering, Rensselaer Polytechnic Institute

NNIN REU Site: Nano Research Facility, Washington University in St. Louis, MO

NNIN REU Principal Investigator(s): Dr. Lan Yang, Electrical and Systems Engineering, Washington University in St. Louis

NNIN REU Mentor(s): Dr. Sahin Ozdemir, Electrical and Systems Engineering, Washington University in St. Louis

Contact: zakrem@rpi.edu, yang@ese.wustl.edu

Optical biosensors rely on the interaction between light and molecules, which can be significantly enhanced by a resonant structure. A variety of optical resonators have been investigated for ultra-sensitive and label-free biosensing. Among them, whispering-gallery-mode (WGM) resonators, in which light is trapped in circulating orbits by total internal reflections, hold the highest quality.

Light can circulate millions of times allowing a single particle to cause noticeable changes in the transmission spectrum of outgoing light. Theoretically, WGM biosensors can provide high resolution, label-free kinetics of amyloid seeding and nucleation, and prion infection; however, before these experiments can be realized, higher *Q*-factors and sensitivities in water must be achieved.

We developed a novel fabrication method for a capillary-based high-*Q* WGM resonator by employing pressurized inert gas to overcome the effects of surface tension during the capillary pulling process. Current fabrication protocols produce rough interior surfaces resulting in lower *Q*-factors due to scattering losses. Using our protocol, we produced capillaries with much less interior roughness and showed that there is a near-linear relationship between gas pressure and capillary wall-thickness.

Currently, we are attempting to achieve sub-micron wall-thicknesses and testing the *Q*-factor and sensitivity of smooth capillaries supporting WGM.

Fabrication of Sub-Micron Lateral Spin Valves

Alayne M. Lawrence
Chemical Engineering, Xavier University of Louisiana

NNIN REU Site: Minnesota Nanotechnology Cluster, University of Minnesota-Twin Cities
NNIN REU Principal Investigator(s): Professor Paul Crowell, Physics, University of Minnesota-Twin Cities
NNIN REU Mentor(s): Michael Erickson, Physics, University of Minnesota-Twin Cities
Contact: alawren1@xula.edu, crowell@physics.umn.edu

This research project focuses on sub-micron lateral spin valves, which are devices that allow us to measure spin injection and relaxation in metallic structures. Initial progress on the fabrication of these lateral spin valves of high purity, high conductivity transport channels of copper, aluminum, and silver will be presented. These high quality materials are prepared by annealing high purity wires and foils to form the transport channel then ferromagnetic contacts are deposited on. The resistivity measurements from annealing can give insight into material quality. Also, fabricating devices with high residual resistivity ratio (RRR) and conductivity allows for comparison with existing devices of similar materials with high purity at a lower RRR.

This comparison may lead to better understanding of the role of grain structure on spin relaxation that can be modified by annealing. In addition, this may serve to ultimately develop a new process to deposit ferromagnetic contacts on a single crystal wire.

Hybrid Silicon Microring Lasers

Daryl T. Spencer
Engineering Physics, University of Tulsa

NNIN REU Site: Nanotech @ UCSB, University of California Santa Barbara
NNIN REU Principal Investigator(s): John Bowers, Electrical and Computer Engineering, UCSB
NNIN REU Mentor(s): Di Liang, Electrical and Computer Engineering, UCSB
Contact: daryl-spencer@utulsa.edu, bowers@ece.ucsb.edu

Silicon photonics is an important and progressive field for developing low cost, high speed optical devices on a Si substrate. Integrating on-chip optical interconnects with modern Si electronics can realize faster and more power efficient data communications in future microprocessors and other emerging applications.

We demonstrate a hybrid silicon microring laser device utilizing active InP-based epitaxial layers integrated on a Si-on-insulator substrate. The ring resonators exhibit compact structure with diameters of ≤ 50 μm. Laser emission is evanescently coupled to a Si waveguide and captured by on-chip photodetectors. Successful continuous-wave lasing has been observed with a minimum electrical pump current of < 5 mA at 10°C and maximum power output > 500 μW at 20°C. Temperature dependent studies were also conducted up to a safe operating temperature of 65°C. Lasing at 1.53 μm shows good spectrum purity with a < 0.04 nm linewidth (limited by the resolution of the optical spectrum analyzer), 4.2 nm free spectral range, and > 40 dB extinction ratio at 20°C. Unidirectional bistability, a unique characteristic of circular lasers, is also observed.

The devices are a promising candidate for future applications in optical interconnects, memory, and all optical processing.

Fabrication and Characterization of Catalytic Nanomotors

Christine Burdett
Chemical Engineering and Spanish, North Carolina State University

NNIN REU Site: ASU NanoFab, Arizona State University

NNIN REU Principal Investigator(s): Dr. Jonathan Posner, Mechanical Engineering, Chemical Engineering, Arizona State University

NNIN REU Mentor(s): Jeffrey Moran, Mechanical Engineering, Arizona State University

Contact: cmburdet@ncsu.edu, jposner@asu.edu, jeffrey.moran@asu.edu

Platinum-gold bimetallic nanorods can swim autonomously in aqueous hydrogen peroxide solutions. The nanorod locomotion is caused by the asymmetric electrochemical reactions on the platinum and gold surfaces. These reactions generate an electric field and an electric body force that drives the nanomotor through the surrounding viscous liquid.

The focus of this project is to fabricate and study the motion of nanomotors. Specifically, the speed and behavioral changes that occur when polymers and different metals are added to the Pt/Au nanorods are investigated in an effort to describe the physics of the nanomotors.

Nanomotors with nickel segments exhibit ferromagnetic properties, allowing control of their direction of motion using magnetic fields; we fabricated ferromagnetic nanomotors with varying nickel segment lengths to determine which efficiently controls movement. Finally, we found that traditional platinum-gold nanomotors can be oriented by inducing an electric dipole force using an AC electric field.

Residual Stress of Atomic Layer Deposited Tungsten

Steve Brown
Physics and Mathematics, University of Minnesota

NNIN REU Site: Colorado Nanofabrication Laboratory, University of Colorado at Boulder

NNIN REU Principal Investigator(s): Victor Bright, Mechanical Engineering, University of Colorado at Boulder

NNIN REU Mentor(s): Bradley Davidson, Mechanical Engineering, University of Colorado at Boulder

Contact: brow2178@umn.edu, Victor.Bright@colorado.edu

Because tungsten is a refractory metal, its use as a structural material in micro or nano-electromechanical devices allows the devices to operate at high temperatures. Atomic layer deposition tungsten (WALD) has the additional advantage of low deposition temperatures (120°C) in addition to the perfectly conformal coating of all surfaces – even those that have been undercut.

In designing WALD devices it is important to know the residual stress, which results from the mismatch between the thermal expansion coefficients of the deposited tungsten and the underlying material. Residual stress can cause cantilever structures to curl toward or away from the substrate changing working distance and function of a device. In addition, residual stress can affect the resonant frequency, which is critical for sensor applications. Characterization of the residual stress should lead to better models and simulations of devices, allowing for the proper design of a functioning WALD device. Using passive test structures the residual stress of WALD deposited on nickel was measured.

Optimization and Bioconjugation of Silicon Nanowire Biosensors

Jacob Sadie
Electrical Engineering, Clemson University

NNIN REU Site: Nanotechnology Research Center, Georgia Institute of Technology
NNIN REU Principal Investigator(s): Dr. James Meindl, Electrical Engineering, Georgia Institute of Technology
NNIN REU Mentor(s): Ramasamy Ravindran, Electrical Engineering, Georgia Institute of Technology
Contact: jake.sadie@gmail.com, james.meindl@mirc.gatech.edu

Silicon nanowire (SiNW) biosensors are highly sensitive nanoscale field-effect transistors (FETs). Because the channel width is on the nanometer scale (either 50 or 100 nm), minor environmental alterations elicit obvious changes in the transistor's conductivity. With proper bioconjugation techniques, the presence of bound molecules in buffer solutions will affect the charge at the surface of the nanowires, changing the conductivity of the wire and indicating the sensing event.

Our process is a top-down fabrication technique including electron-beam lithography for the patterning of silicon nanowires. Our project focused on optimizing the fabrication process by (a) adjusting the electron-beam resist application and etching procedures, (b) modifying the annealing procedures before and after electrode deposition, and (c) determining optimal conditions for pH sensing and protein bioconjugation. Our project has currently produced substantial results for the etch characteristics of electron-beam resist and annealing adjustments, while work continues toward effective bioconjugation processes.

Energy Recoverable Operation of Lateral Nanoelectromechanical (NEM) Aluminum Switches

Vivian Feig
Chemical Engineering, Columbia University

NNIN REU Site: Stanford Nanofabrication Facility, Stanford University

NNIN REU Principal Investigator(s): Roger T. Howe, Electrical Engineering, Stanford University

NNIN REU Mentor(s): Roozbeh Parsa, Electrical Engineering, Stanford University, J. Provine, Electrical Engineering, Stanford University

Contact: vrf2103@columbia.edu, rthowe@stanford.edu

In designing integrated circuits, nanoelectromechanical (NEM) switches are advantageous because, unlike transistors, they have nearly zero power dissipation in their off state. An energy recoverable (ER) design that takes advantage of stored elastic energy in the mechanical switch can further decrease total power used by lowering the voltage required for operation.

In this project, we constructed a lateral cantilever beam that switches between two symmetric sense electrodes (drains) when voltage is applied to two symmetric drive electrodes (gates). To avoid conductivity issues caused by the spontaneous oxidation of silicon beams in air, we used aluminum instead of silicon to construct our device on a quartz substrate. Silicon was used as a sacrificial release layer for the aluminum. Devices were tested by applying various voltages to the beam and gates, with subsequent current flow through the drains indicating beam contact.

We aim to demonstrate ER operation with this setup, and anticipate achieving a significant decrease in switching voltage as compared to a traditional NEM switch.

The Growth of Silicon, Germanium, Si_xGe_{1-x} and Various Polytypes of Silicon Carbide Nanowires

Keara Harris
Electrical Engineering, Hampton University

NNIN REU Site: Howard Nanoscale Science and Engineering Facility (HNF), Howard University
NNIN REU Principal Investigator(s): Dr. Gary Harris, Electrical Engineering, Howard University
NNIN REU Mentor(s): Crawford Taylor, Electrical Engineering, Howard University
Contact: keara.harris@pipeline.hamptonu.edu, gharris@msrce.howard.edu

The silicon germanium (SiGe) alloy has played an important role in the semiconductor industry because of its inexpensive production and high power capabilities. Silicon carbide (SiC) has also played an important role due to its high thermal conductivity and wide energy band gap.

In this study silicon, germanium, Si_xGe_{1-x} and various polytypes of SiC nanowires were grown via a chemical vapor deposition (CVD) reactor.

Nanowires are 1-dimensional nanostructures which have very interesting and high mobility properties. Polytypes of SiC were grown on silicon substrates with a nickel (Ni) catalyst using silane and propane. The polytypes were achieved by varying the temperature of the CVD reactor during growth. In doing this, we changed the phase of the nanowires from cubic SiC (3C-SiC) to hexagonal SiC (6H-SiC).

The silicon, germanium, and Si_xGe_{1-x} structures were grown using silane and germane. X-ray and other characterization techniques were used to examine the structures and nature of the 1-dimensional systems.

This work is sponsored by a grant from the National Science Foundation (NSF) through the National Nanotechnology Infrastructure Network Research Experience for Undergraduates (NNIN REU) Program.

Atomic Layer Deposition of High-k Gate Dielectrics for Thin Film Transistors

Du Nguyen
Physics, Michigan State University

NNIN REU Site: Lurie Nanofabrication Facility, University of Michigan, Ann Arbor

NNIN REU Principal Investigator(s): Jamie Phillips, Electrical Engineering and Computer Science, University of Michigan

NNIN REU Mentor(s): Jeffrey Siddiqui, Electrical Engineering and Computer Science, University of Michigan

Contact: nguye191@msu.edu, jphilli@umich.edu

Transparent insulating oxides with high dielectric constant are desired for thin film transistors that form the basis of current flat panel displays and future flexible and transparent electronics. This project uses atomic layer deposition (ALD) in order to grow these oxide films.

ALD deposits precisely one monolayer of film with every cycle so that thicknesses can be controlled at the atomic level. An Oxford OpAL ALD tool was used in this work to deposit thin films of Al_2O_3 and HfO_2 under varying parameters of temperature, plasma power, and pressure. In addition, the effects of thermal annealing the films after deposition were examined. Optimal growth parameters were found in order to maximize dielectric constant and minimize leakage current through the films, as these parameters are critical in determining the ultimate performance of thin film transistors.

The results of the study will be applied to current research on zinc oxide and zinc telluride thin film transistors.

Fabrication of Nanohole Arrays using Nano-Imprint Lithography

Axel Palmstrom
Chemical Engineering, University of California Santa Barbara

NNIN REU Site: Minnesota Nanotechnology Cluster, University of Minnesota-Twin Cities

NNIN REU Principal Investigator(s): Sang-Hyun Oh, Electrical and Computer Engineering, University of Minnesota

NNIN REU Mentor(s): Si Hoon Lee, Biomedical Engineering, University of Minnesota;
Hyungsoon Im, Electrical and Computer Engineering, University of Minnesota

Contact: apalmstrom@umail.ucsb.edu, sang@umn.edu

Surface plasmons are electromagnetic waves resulting from the excitation of a metallic film at the interfaces between the film and a dielectric from a laser. At a specific incident angle of light to the medium, there is a maximum in surface plasmon intensity and a minimum in reflected light intensity from the surface. This is known as surface plasmon resonance (SPR). SPR can be used in a real-time biosensing with uniform nanostructures in a gold film [1]. A method of fabricating nanostructures, specifically nanohole arrays, is necessary for this biosensing application.

Current fabrication methods for nanohole arrays include focused ion beam (FIB) milling and electron beam lithography (EBL). These techniques are slow and expensive. Cheaper and more efficient nanohole fabrication techniques are needed for SPR biosensing. Nanosphere lithography combined with sputtering techniques can do this [1], however the process requires numerous steps and lacks the consistency desired for production. Nanoimprint lithography offers the advantages of low cost, high throughput, and uniformity associated with the imprinting process. Nano-imprint results from masks fabricated with both the use of polystyrene nanospheres combined reactive ion etching (RIE) and with EBL will be discussed.

References:

[1] Lindquist et al (2009)"Sub-micron resolution surface plasmon resonance imaging enabled by nanohole arrays with surrounding Bragg mirrors for enhanced sensitivity and isolationî Lab on a chip, 9, 382-387 (2009).

Elemental Analysis of Ge-Si_xGe_{1-x} Core-Shell Nanowire Heterostructures

Arrielle Opotowsky
Physics and Astronomy, Louisiana State University

NNIN REU Site: Microelectronics Research Center, The University of Texas at Austin
NNIN REU Principal Investigator(s): Prof. Emanuel Tutuc, Electrical Engineering, University of Texas at Austin
NNIN REU Mentor(s): Kamran Varahramyan, Electrical Engineering, University of Texas at Austin
Contact: aopoto1@tigers.lsu.edu, etutuc@mer.utexas.edu

The study and use of semiconductor nanowires is of interest in many electronic, photonic applications, as well as biological and chemical sensing. The ability to engineer the electronic properties by altering the band structure, combined with the reduced dimensions, make nanowire heterostructures attractive as building block for low-power, high speed electronics.

Here we investigate Ge-Si_xGe_{1-x} core-shell nanowire heterostructures, where the Si_xGe_{1-x} shell is *in-situ* grown on the Ge nanowire cores using ultra-high-vacuum chemical vapor deposition. Transmission electron microscopy shows that the Si_xGe_{1-x} shell is single crystal and grows epitaxially on the Ge cores. To determine the shell thickness and elemental composition of the nanowire heterostructures we employ energy dispersive x-ray spectroscopy, and electron energy-loss spectroscopy.

Our data shows that the Si/Ge relative content of the Si_xGe_{1-x} shell can be tuned depending on the growth conditions, which enables radial band engineering in these nanowire heterostructures.

Microfluidics Guided Self-Assembly of Liposomes

Tiffany Moeller
Chemical Engineering, University of Nebraska-Lincoln

NNIN REU Site: Cornell NanoScale Science & Technology Facility, Cornell University
NNIN REU Principal Investigator(s): Carl Batt, Department of Food Science, Cornell University
NNIN REU Mentor(s): Matthew Kennedy and Dickson Kirui, Department of Food Science, Cornell University
Contact: tm395@cornell.edu, cab10@cornell.edu

Liposomes in the range of 100 to 500 nm were created using a microfluidic flow-focusing device by varying composition and flow rates of the lipid and sheath fluids. Composed of a hydrophobic lipid bilayer enveloping a hydrophilic compartment, liposomes can be engineered to encapsulate magnetic nanoparticles. These magnetoliposomes can induce hyperthermia, allowing a burst-release of encapsulated therapeutics. The project aims were (1) optimizing the reagent parameters to modify liposome size and morphology and (2) encapsulating nanoparticles in the liposomes. The liposomal synthesis and encapsulation were accomplished using a three-dimensional microfluidic focusing manifold to enhance the liposomes' monodispersity which is important for in vivo pharmacokinetics. Focusing the lipids in the microchannel center and surrounding them by an aqueous sheath fluid directs liposome self-assembly. At flow rate ratios (FRRs)—sheath to lipid solution—from 10 to 25, increasing the sheath's KCl concentration from 0.10 to 100.0 mM increased the liposomes' average size from 120 to 470 nm. At the same FRRs a change from 0.10 to 10.0 mM in lipid concentration decreased their size from 215 to 120 nm. FRRs less than ten yielded large aggregates and polydisperse liposomes. Nanoparticles' composition, stabilizing surfactant, and encapsulation procedure were varied to optimize their encapsulation.

Fabrication of Grating Couplers and Optical Waveguide Sensors

Edgar Garay
Electrical Engineering and Physics, Florida International University

NNIN REU Site: Nanotechnology Research Center, Georgia Institute of Technology

NNIN REU Principal Investigator(s): David S. Gottfried, Nanotechnology Research Center, Georgia Institute of Technology

NNIN REU Mentor(s): Janet Cobb-Sullivan, Nanotechnology Research Center, Georgia Institute of Technology

Contact: efgaray@hotmail.com, david.gottfried@mirc.gatech.edu

A method using nanoimprint lithography (NIL) was developed in order to fabricate grating couplers that will be used in a chemical sensor based on optical planar waveguide interferometry.

A light beam propagating through a waveguide has an evanescent field extending from the waveguide into the cover layer and substrate. The phase of the propagating light is sensitive to index of refraction changes. By applying a chemically selective film on top of the waveguide and optically combining this with a reference beam, a sensor can be fabricated. Grating couplers offer an inexpensive and simple solution to the difficult task of coupling light into the thin waveguides needed for the sensor. Further investigation is needed in order to simplify the fabrication process to improve the yield and reduce the cost of the sensors.

Previously, a UV curable polymer was imprinted with the grating pattern using a template prepared by e-beam lithography. This pattern was then utilized as an etch mask in order to fabricate the grating couplers in a quartz substrate. However, optical and thermal characteristics of the polymer may make it suitable for use as the substrate directly, with the waveguide deposited directly over the imprinted grating structures.

Fabrication and Characterization of Nanobeam Resonators with Waveguides

Arolyn Conwill
Physics, Pomona College

NNIN REU Site: Center for Nanoscale Systems, Harvard University

NNIN REU Principal Investigator(s): Prof. Marko Lončar, Engineering and Applied Sciences, Harvard University

NNIN REU Mentor(s): Ian Frank (2007 NNIN REU at Harvard), School of Engineering and Applied Sciences, Harvard University

Contact: amc02006@mymail.pomona.edu, loncar@seas.harvard.edu

This project focuses on the optical properties of nanobeam resonators, a type of one-dimensional photonic crystal that can confine light at sub-wavelength scales with incredibly high quality factors (theoretical *Q*s are on the order of 10^7). These devices have potential applications in nanoscale chemical sensing, optical switching, lasers, low power nonlinear optics, cavity quantum electrodynamics (QED), and light-matter coupling.

Previously, these resonators have been characterized using a resonant scattering technique; however, the coupling of the incident laser beam from free space restricts the number of modes available for excitation. Our new design incorporates waveguides onto the ends of the resonator cavity, allowing us to measure a broader set of resonant modes by coupling the end of the waveguide to a pulled optical fiber carrying the evanescent laser beam.

The cavity consists of a silicon nanobeam with a series of holes including a perturbation in spacing at the center; the geometry determines the characteristic band gap and resonant modes of the cavity. The fabrication process uses electron beam lithography to write the cavity pattern to an SOI wafer covered in a negative resist and employs reactive ion etching to transfer the pattern to the device layer of the wafer.

Fabrication of Silicon Nitride Waveguides

Takia Wheat
Chemistry, Jackson State University

NNIN REU Site: Center for Nanoscale Systems, Harvard University
NNIN REU Principal Investigator(s): Marko Lončar, Engineering and Applied Sciences, Harvard University
NNIN REU Mentor(s): Parag B. Deotare, School of Engineering and Applied Sciences, Harvard University
Contact: takia.m.wheat@jsums.edu, loncar@seas.harvard.edu

Over the years, there has been an ongoing demand for faster, better, and less expensive computer systems. Microelectronics has so far offered quality solutions but has now reached its limitations. Nanophotonics, is one of an alternative to microelectronics. Owing to its much larger bandwidth, it has high potential for providing solution to faster computer systems through the manipulation of light which is channeled using a waveguide. These waveguides, based on total internal reflection are able to transport light from one area to another.

Once light is between two mediums of lower refractive indices, it is reflected back and trapped which can then be used in integrated optics to link together various optical devices and components. In this work, we report the fabrication of silicon nitride waveguides which can operate at standard telecom wavelengths. The fabrication of a waveguide mainly involved nanofabrication processes like ebeam lithography which was used for defining the waveguides followed by reactive ion etching (RIE) to transfer the pattern onto the silicon nitride surface. Optimization of the RIE etch chemistry was carried out to generated straight and smooth walled waveguides.

Silicon Migration for Nanophotonic Elements

Matt Strathman
Electrical Engineering, Montana State University

NNIN REU Site: Stanford Nanofabrication Facility, Stanford University

NNIN REU Principal Investigator(s): Roger Howe, Electrical Engineering, Stanford University

NNIN REU Mentor(s): J Provine, Electrical Engineering, Stanford University;
Il Woong Jung, Electrical Engineering, Stanford University

Contact: matt827657@gmail.com, rthowe@stanford.edu

Photonic crystals made from silicon have many applications such as waveguides, sensors and broadband mirrors. Photonic crystals are periodic arrangements of dielectric materials, in our case a periodic array of holes etched into a silicon substrate, that have special optical properties. These photonic crystals are fabricated using the GOPHER process, which is the Generation Of PHotonic Elements by RIE (Reactive Ion Etching).

We explored one way of improving the performance of these photonic crystals using the migration of single crystal silicon. More specifically we investigated the use of annealing, which may be done in different ambients including hydrogen, to reflow the silicon and hence reach a low surface energy state. This had the potential to improve the performance of the devices as well as decrease variations in the devices from the fabrication process. Scanning electron microscopy and optical spectroscopy were used to study the devices and the extent that the reflow has affected their structure and optical performance.

Optimization of the design of these photonic crystals would increase the efficiency of the optical devices, and because the process is CMOS compatible, the utilization of the process to fabricate optical devices could lead to many more new and interesting applications.

Modeling Intermediates in Prion Protein Fibril Formation

Stephanie Lau
Chemistry, Wellesley College

NNIN REU Site: Center for Nanotechnology, University of Washington, Seattle

NNIN REU Principal Investigator(s): Valerie Daggett, Bioengineering, University of Washington

NNIN REU Mentor(s): Marc van der Kamp, Bioengineering, University of Washington

Contact: slau@wellesley.edu, daggett@u.washington.edu

The misfolding and aggregation of the prion protein has been implicated in several infectious neurodegenerative diseases such as Creutzfeldt-Jakob Disease in humans and bovine spongiform encephalopathy in cows. Deposits of insoluble prion protein fibrils can often be detected in affected humans. However, before forming fibrils, the misfolded prion proteins first aggregate into soluble oligomers—known as protofibrils—that are responsible for cellular toxicity and disease infectivity. The structure of these toxic and infectious agents in prion diseases remains elusive due to the difficulty in obtaining high-resolution experimental data.

From molecular dynamics simulations of the prion protein under misfolding conditions, we selected potentially misfolded conformations. Based on these conformations and experimental data suggesting likely contact regions between monomers, we constructed several different protofibril models. This was done by manually docking monomers together to create a cross-monomer β-sheet. These models were then compared with the available experimental data to assess if they are reasonable models for the toxic intermediates.

Results from this project will provide insights into how the native prion protein may misfold and assemble into pre-fibrillar aggregates.

Raman Topography Studies of Eutectic Systems of Strontium Ruthenate (214) and Ruthenium

Eric Hao
Engineering, University of California, Berkeley

NNIN REU Site: Penn State Nanofabrication Facility, The Pennsylvania State University
NNIN REU Principal Investigator(s): Ying Liu, Department of Physics, Pennsylvania State University
NNIN REU Mentor(s): Neal Staley, Conor Puls, Department of Physics, Pennsylvania State University
Contact: eric_hao@berkeley.edu, liu@phys.psu.edu

Raman spectroscopy is a useful tool in characterizing materials. It relies on the unique bonding structure of materials in order to discriminate and classify them from each other. The user essentially shines a laser (usually in the visible spectrum) onto his or her sample. The incoming photons excite the electrons in the material from the conduction band to the valence band. The excited electrons then inelastically scatter, emitting phonons with specific energies. The electrons then backscatter, and fall back down to the conduction band, emitting a photon with slightly less energy. From there, one can recapture the reflected light in a charge-coupled device and measure the resultant shift.

This method is useful in not only classifying materials, but also in detecting the effects of interface. Specifically, we were interested in measuring the interface effects in eutectic systems of strontium ruthenate 214 (the first and only known Cu-free layered perovskite superconductor) and ruthenium.

Pillar Array Polymer Template for Solar Cells

Travis Rosmus
Chemistry Department, Saint Francis University in Loretto

NNIN REU Site: Penn State Nanofabrication Facility, The Pennsylvania State University

NNIN REU Principal Investigator(s): Heayoung Yoon, Dr. Theresa Mayer, Electrical Engineering Department, Penn State University

Compared to the conventional planar structure, the geometry of high-aspect-ratio pillar arrays can offer the potential to achieve a low cost, commercially viable route to the production of high efficiency solar cells, in that the direction of light absorption is decoupled from that of carrier collection. This project will explore the design and process to fabricate a pillar array template using polymers. We will also investigate the properties of the template including hardness test and FESEM analysis.

We studied the basics behind the etching process and the creating of a polymer template for solar cells. Templates were created by spinning a certain thickness of polyimide onto oxidized silicon pillar arrays followed by the removal of the oxide using buffered oxide etchant (BOE), to release the polymer template from the substrate. We used different spinning speeds and graphed the results in a *Thickness vs RPMs* graph. From there, we created the protocol that yielded the appropriate template.

This project introduced the intern to working in a real lab environment with access to equipment not available at Saint Francis. It has also allowed the intern to work under a graduate student and be a part of a research team on a project of interest.

Plasmonic Focusing of Light

Chelsea Frid
Material Science and Engineering, Michigan State University

NNIN REU Site: Lurie Nanofabrication Facility, University of Michigan, Ann Arbor
NNIN REU Principal Investigator(s): Mona Jarrahi, Electrical Engineering, University of Michigan
NNIN REU Mentor(s): Christopher Berry, Electrical Engineering, University of Michigan
Contact: fridchel@msu.edu, mjarrahi@umich.edu

The goal of this project is to develop a terahertz detector. Terahertz is a portion of electromagnetic spectrum that lies between the microwave and optical ranges. The device consists of a periodic array of schottky diodes with interdigitated comb fingers on a low-resistivity gallium arsenide (GaAs) substrate. Schottky diodes are used for terahertz detection because their nonlinear current-voltage characteristic aid in the detection of high frequency signals.

In operation, the alternating electrodes are connected to a voltage source. The sinusoidal electric field of the terahertz radiation modifies the average voltage difference between the electrodes, due to the nonlinear characteristics of the diode. The periodic arrangement of the schottky diodes assists in collecting a large portion of the incident terahertz radiation.

Due to time constraints, the testing of the final device was not fully completed. In this paper, we present the process and initial results obtained in the creation of this device.

Atomic Force Microscope Direct-Write of Carbon Nanowires: Structure Optimization

Jacqueline Collette
Materials Science and Engineering, Arizona State University

NNIN REU Site: Center for Nanotechnology, University of Washington, Seattle
NNIN REU Principal Investigator(s): Marco Rolandi, Materials Science and Engineering, University of Washington
NNIN REU Mentor(s): Jessica Torrey, Materials Science and Engineering, University of Washington
Contact: jacqueline.collette@asu.edu, rolandi@u.washington.edu

The fabrication of nanoscale devices requires precision in positioning and connecting nanoscale components into complex geometries. Atomic force microscope (AFM) direct deposition of nanoscale materials occurs via field-induced localized chemical reactions of a liquid precursor in the region between the AFM tip and the substrate. This method offers highly precise positioning and the ability to deposit complex geometries for device integration.

This work focuses on the AFM direct deposition of carbon nanowires (CNWs) from n-octane and their characterization. Previous work in the group has examined changes in sp^2/sp^3 bond ratios in CNWs as a function of annealing temperature with the photoemission electron microscope (PEEM). With increasing temperature, sp^3 dominant, diamond-like carbon transforms into sp^2 prevalent, graphite-like carbon.

This work aims to corroborate the PEEM results with electrical conductivity measurements by integrating the CNWs into devices and measuring the change in conductivity as a function of annealing temperature. Investigations focus on parameters of the direct-write and annealing processes, characterization of the deposited nanowires using AFM and the scanning electron microscope, as well as analysis of electrical behavior.

Role of Reactive Oxygen Species in Nanotoxicity

Sarah Connolly
Biochemistry/Microbiology, University of Florida

NNIN REU Site: Minnesota Nanotechnology Cluster, University of Minnesota-Twin Cities
NNIN REU Principal Investigator(s): Christy Haynes, Chemistry, University of Minnesota
NNIN REU Mentor(s): Melissa Maurer-Jones, Chemistry, University of Minnesota
Contact: sarahsconnolly@ufl.edu, chaynes@umn.edu

This project focuses on observing the presence of reactive oxygen species (ROS) in mouse fibroblast model cells when exposed to nano-titanium dioxide (nTiO_2) utilizing a series of fluorescent probe assays: 4-((9-acridinecarbonyl)amino)-2,2,6,6-tetramethylpiperidin-1-oxyl (TEMPO-9-AC), Singlet Oxygen Sensor Green, and 2',7'-dichlorodihydrofluorescein diacetate (H_2DCFDA).

ROS can cause oxidative stress in a cell and can cause cell dysfunction, mutation, or even death. Each probe detects one, or several, ROS including hydroxyl radical, singlet oxygen, superoxide, and hydrogen peroxide. Assays were performed in 96-well plates using a fluorescent plate reader where cells were exposed to varying concentrations of nTiO_2 (12.5-400 µg/mL) for 24, 48, or 72 hours. Following exposure, the fluorescence intensity of the probe species was measured and compared to a calibration curve. Fluorescence intensity tended to increase as nTiO_2 concentration increased, showing insignificant difference between time points, indicating more ROS is generated with greater amounts of nTiO_2.

Cellular uptake of the nanoparticles was also studied using inductively coupled plasma-atomic emission spectroscopy analysis to correlate ROS generation with cellular internalization of nTiO_2. While commonly used cellular viability assays show that the nTiO_2 nanoparticles had minimal effect on cell viability, the elevated uptake and increased ROS levels may have harmful effects on cell function, requiring further investigation.

DNA Electrophoresis in Sparse Ordered Obstacle Arrays

Alyssa Terry
Biomedical Engineering, Mississippi State University

NNIN REU Site: Minnesota Nanotechnology Cluster, University of Minnesota-Twin Cities

NNIN REU Principal Investigator(s): Kevin Dorfman, Chemical Engineering and Materials Science, University of Minnesota-Twin Cities

NNIN REU Mentor(s): Jia Ou, Chemical Engineering and Materials Science; Daniel Olson, Chemical Engineering and Materials Science, University of Minnesota-Twin Cities

Contact: abt66@msstate.edu, dorfman@umn.edu

Engineering faster methods for deoxyribonucleic acid (DNA) separation is critical for the future of disease diagnosis and forensic work. To date, electrophoresis for DNA separation can only be performed on samples with fewer than around 20,000 base pairs using constant field gel electrophoresis. By increasing the pore size of traditional electrophoresis media, longer DNA with more base pairs can also be separated under a dc field in microfluidic devices.

This study focuses on two main challenges: optimizing fabrication methods for creating micro-features on silica using the facilities available in the UMN fabrication center and understanding the post-collision mechanism of the DNA molecules.

To study the DNA collision, first a procedure for creating an ordered hexagonal array in silica with 1 µm features had to be developed. Scanning electron microscopy was used to inspect the effectiveness of the fabrication procedure. For the electrophoresis experiments, the DNA was dyed with YOYO-1 and then placed in the chip under an electric field. An inverted microscope controlled by LabVIEW in addition to MATLAB software were used to image and analyze the DNA during separation. Using the images recorded from the experiments, the DNA was analyzed for collisions, shape upon impact, velocity and time to relaxation.

Engineering Hcp1 Protein Nanotubes for Non-Specific DNA Binding

Keith Olson
Biochemistry and Psychology, Beloit College

NNIN REU Site: Center for Nanotechnology, University of Washington, Seattle
NNIN REU Principal Investigator(s): Joseph Mougous
NNIN REU Mentor(s): Julie Silverman, Microbiology, University of Washington
Contact: dukeball22@gmail.com, mougous@u.washington.edu

Proteins are ideal materials for biological and industrial applications in nanotechnology because they are inexpensive, biocompatible and can easily be modified. Hcp1 – a homohexameric ring protein secreted by *Pseudomonas aeruginosa* – can form nanotubes through ring-ring stacking interactions. With an inner pore of 4 nm, these tubes show potential use for deoxyribonucleic acid (DNA) binding, drug encapsulation and scaffolds for nanowire synthesis.

This research project focuses on modifying the inner pore of Hcp1 to bind DNA non-specifically. These subunits can then be used to assemble DNA encapsulating tubes for DNA-processing scaffolds, vector drug delivery and microarray analysis.

For example, copper(II) complexes could be derivatized to the inside of the tubes to catalytically cut DNA into standard lengths. We used site-directed mutagenesis to introduce positively charged lysine residues to promote non-covalent interactions with the negatively charged backbone of DNA. Hcp1-DNA interactions were measured by DNA-protein gel shift assays, filter binding assays and electron microscopy.

This work demonstrates the preliminary steps towards producing DNA encapsulating tubes.

Controlling Cell Functions with Light on Tip

Richard Purvis
Engineering Physics, Tulane University

NNIN REU Site: Microelectronics Research Center, The University of Texas at Austin
NNIN REU Principal Investigator(s): John X. J. Zhang, Biomedical Engineering, University of Texas
NNIN REU Mentor(s): Yuyan Wang, Biomedical Engineering, University of Texas
Contact: rpurvis@tulane.edu; john.zhang@engr.utexas.edu

The objective of this project is to manipulate cell membrane proteins, through a nanofabricated plasmonic scanning probe tip mounted in a near-field scanning optical microscope (NSOM).

For this REU program, calibration of the plasmonic enhanced scanning probe tip was performed by measuring the dependence of exposure depth on exposure time in photoresist (AZ5209E) spun onto a glass substrate. Models were constructed using COMSOL finite element method (FEM) for comparison, which is then extended to evaluate the thermal and optical effects of the probe on a living cell.

To prepare for protein stimulation using the plasmonic tip, we also demonstrated a microcontact printing technique to pattern protein on glass substrate using a polydimethylsiloxane (PDMS) stamp. The resulting protein layers thickness and uniformity were evaluated using AFM and SEM.

The preliminary experiments and simulations well prepare for further applying the plasmonic probe tip with high spatio-temporal resolution for local optical perturbation of membrane proteins in a biological cell.