NNIN

Nanoscale Science, Engineering & Technology

The 2011 NNIN REU Convocation

NSF

August 10-13, 2011

Georgia Institute of Technology

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Georgia Tech Nanotechnology Research Center

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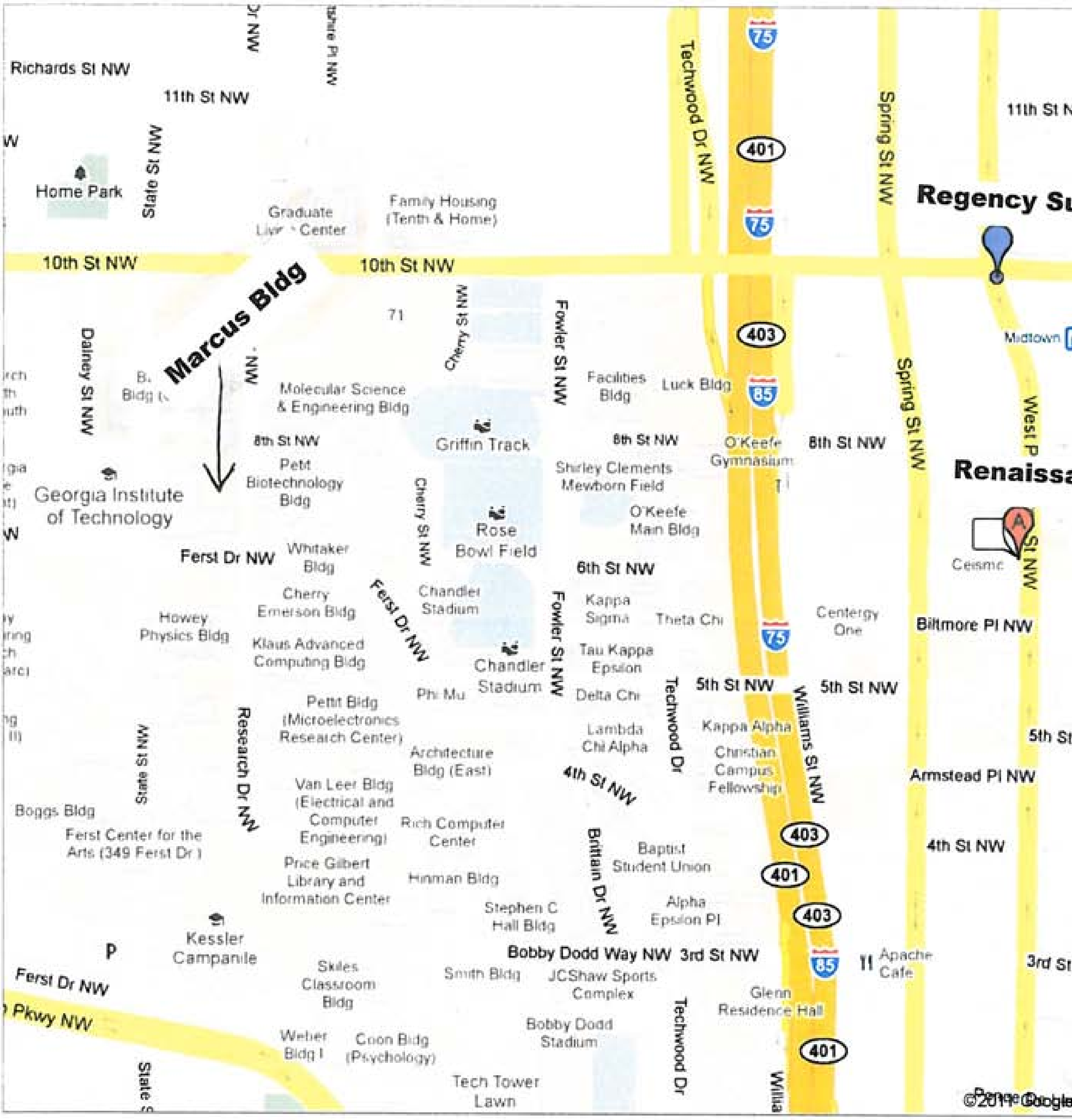

2011 NNIN REU Convocation
Georgia Institute of Technology

Wednesday, August 10, 2011

2:00-6:00 p.m. **Intern check-in at Regency Suites Hotel**
Use MARTA to get from the airport to the hotel

6:30-7:30 p.m. **Scavenger Hunt for Interns (The hunt starts at the hotel – please gather in the lobby at 6:15 p.m.)**
Registration at Marcus Nanotechnology Building

7:30-9:00 p.m. **Welcome and Pizza Party (Transportation via GT Trolley or walking)**

Thursday, August 11, 2011

6:30-8:30 a.m. **Breakfast for interns at hotel (none at convocation)**

8:30-8:45 a.m. **Welcome by Dr. Gary May, Dean of Engineering Georgia Institute of Technology**
Announcements

8:45-9:45 a.m. **(12 talks total)**

Session M 1 Marcus Nanotechnology Building (6 talks)

Moderator: Nancy Healy

Session B 1 Petit Biotechnology Building (6 talks)

Moderator: Mike Deal

8:45 a.m. Noelia Almodovar — NNIN REU Site: Georgia Institute of Technology
Surface Wettability Induced by Nanofilm on Titanium Surface and Osteoblastic Cell Morphology . . . . *page 14*

8:55 a.m. Brittany Alphonse — NNIN REU Site: Georgia Institute of Technology
Fabrication of Microfluidic Devices for Synthesis of Janus Particles . . . . *page 14*

9:05 a.m. Tiffany Dunston — NNIN REU Site: Howard University
Evaluation of Modified Alumina Membrane for Bimolecular Separation . . . . . . *page 15*

9:15 a.m. Julie Chang — NNIN REU Site: The Pennsylvania State University
Fabrication of a Novel Microfilter for Circulating Tumor Cell Enrichment and Culture . . . . *page 15*

9:25 a.m. Vinh Diep — NNIN REU Site: University of California, Santa Barbara
Nanomechanical Properties of Structured Biopolymer Networks . . . . *page 16*

9:35 a.m. Andrew Raebig — NNIN REU Site: University of Michigan, Ann Arbor
Design, Fabrication, and Testing of Hg/Au Microelectrodes for Sensing of Trace Metals in Oceanic Systems . . . . *page 16*

9:45-10:05 a.m. Break at Marcus Nanotechnology Building

10:05-10:55 a.m. (10 talks total)

Session M 2 Marcus Nanotechnology Building (5 talks)

Moderator: Kathy Gehoski

10:05 a.m. William Scheideler — NNIN REU Site: Arizona State University
Fabrication and Characterization of ZnO Nanowire Field Effect Transistors and ZnTe Nanosheet Field Effect Transistors . . . . . . *page 17*

10:15 a.m. Antanica Boneparte — NNIN REU Site: Harvard University
The New Diamond Age: Hetroepitaxial Growth of Diamondsfor Device Applications . . . . *page 17*

10:25 a.m. Carlos Biaou — NNIN REU Site: University of Michigan, Ann Arbor
Ink-Jet Printing of ZiO-Based Semiconductor for Thin Film Transistors . . . . . . *page 18*

10:35 a.m. Kai He — NNIN REU Site: The University of Texas at Austin
Shape-Specific FePt Nanocrystals for Spin-Transfer Torque in Magnetic Tunnel Junctions . . . . *page 18*

10:45 a.m. Emily Griffin — NNIN REU Site University of Michigan, Ann Arbor
Optimization of Switching Layer for Tungsten Oxide Memristor Devices . . . . . . *page 19*

Session B 2 Petit Biotechnology Building (5 talks)

Moderator: James Griffin

10:05 a.m. Amani Alkayyali — NNIN REU Site: Cornell University
Microfluidic Protein Dialysis Device for X-Ray Scattering . . . . *page 19*

10:15 a.m. **Brendon Gobert** **NNIN REU Site: Howard University**
Development of Paper Accelerometers for Cheap Applications .. .. page 20

10:25 a.m. **Kevin Tien** **NNIN REU Site: Stanford University**
Fabrication of Dielectrics for Flexible Thin-Film Electronics . .. . page 20

10:35 a.m. **Lauren Otto** **NNIN REU Site: University of Minnesota-Twin Cities**
Metallic Nanostructure for Surface Plasmon Resonance Biosensing .. .. page 21

10:45 a.m. **Morgan McGuinness** **NNIN REU Site: University of Washington**
Measuring Height Mismatch and Phase Transition Temperatures of Model Lipid Bilayers . .. . page 21

10:55-11:15 a.m. **Break at Marcus Nanotechnology Building**

11:15-11:55 a.m. **(8 talks total)**

Session M 3 Marcus Nanotechnology Building (4 talks)

Moderator: Samantha Andrews

11:15 a.m. **Claire Spradling** **NNIN REU Site: The University of Texas at Austin**
Synthesis of Few Layer Graphene Films of Large Lateral Dimensions .. .. page 22

11:25 a.m. **Nathanial Sheehan** **NNIN REU Site: University of Minnesota-Twin Cities**
Optical and Electron Beam Patterning for Graphene Nanoribbon Devices . .. . page 22

11:35 a.m. **Mariah Szpunar** **NNIN REU Site: University of Colorado Boulder**
Measuring van der Waals Forces in Graphene . .. . page 23

11:45 a.m. **Cassandra Todd** **NNIN REU Site: Cornell University**
Electronic Graphene Devices Through Tip-Based Nanofabrication .. .. page 23

Session B 3 Petit Biotechnology Building (4 talks)

Moderator: Katie Hutchison

11:15 a.m. **Mark Dong** **NNIN REU Site: Harvard University**
Characterization of Optical Devices using a Pigtailed Fiber .. .. page 24

11:25 a.m. **Meagan Pipes** **NNIN REU Site: Stanford University**
Soft Lithographic Fabrication of Bar Chart Phantoms for Axial Resolution Measurements in Optical Coherence Tomography . .. . page 24

11:35 a.m. **David Mallin** **NNIN REU Site: University of Colorado Boulder**
Flexible Membrane Liquid Lens .. .. page 25

11:45 a.m. **Jin Zhang** **NNIN REU Site: University of Michigan, Ann Arbor**
Novel Optical Waveguides for High-Sensitivity Biosensing in Point-of-Care Applications .. .. page 25

11:55-1:00 p.m. Lunch at Marcus Nanotechnology Building
Coordinators Meeting, second floor atrium

1:00-2:00 p.m. (12 talks total)

Session M 4 Marcus Nanotechnology Building (6 talks)

Moderator: Brandon Lucas

1:00 p.m. Michael Akenhead — NNIN REU Site: Washington University in Saint Louis
Sol-Gel Route for Ultra-High-Quality Optical Resonators .. .. page 26

1:10 p.m. Courtney Crouch — NNIN REU Site: University of Washington
Engineering Multifunctional Nanoparticles with Dual Modality Imaging Capabilities .. .. page 26

1:20 p.m. Laura Windmuller — NNIN REU Site: University of Minnesota-Twin Cities
The Calibration of Optical Particle Sizer by Wafer Surface Scanner .. .. page 27

1:30 p.m. Ting Chia Chang — NNIN REU Site: The University of Texas at Austin
Fabrication and Testing of Voltage-Tunable Plasmonic Metamaterials in Mid-Infrared .. .. page 27

1:40 p.m. Dominic Labanowski — NNIN REU Site: University of California, Santa Barbara
Nanoscale Diamond Lenses for Atomic-Scale Sensing .. .. page 28

1:50 p.m. Alex Bryant — NNIN REU Site: Cornell University
Integrated Silicon Nitride Waveguides: Optimization of Fabrication .. .. page 28

Session B 4 Petit Biotechnology Building (5 talks)

Moderator: Nathan Reed

1:00 p.m. Yoshihiro Nakano — NNIN iREG Site: Georgia Institute of Technology
Piezoelectric Micromechanical Vibration Energy Harvester .. .. page 29

1:10 p.m. Andreas Haggerty — NNIN REU Site: Howard University
Using Electron Beam Lithography for Nanowires Transistor Fabrication .. .. . page 29

1:20 p.m. Victoria Savikhin — NNIN REU Site: Cornell University
Surface Characterization of Etched Micro- and Nano-Structures in Silicon for Phonon Heat Transport .. .. page 30

1:30 p.m. Julie Georgiev — NNIN REU Site: The Pennsylvania State University
Patterning of the Metal Induced Crystallization of Amorphous Silicon .. .. page 30

1:40 p.m. Karl Bayer — NNIN REU Site: Stanford University
Adhesion and Cohesion Testing of Square Solar Cells in Inert Environments . . page 31

2:00-2:20 p.m. Break at Marcus Nanotechnology Building

2:20-3:20 Panel Session on Social and Ethical Issues of Nanotechnology, Marcus Nanotechnology Building

Presenters: Dr. Katherine McComas, Cornell University; Ms. Rachel Brockhage, NNIN REU at Cornell University; Dr. Susan Cozzens, Georgia Institute of Technology; Mr. Thomas Woodson, Georgia Institute of Technology

3:20-3:40 p.m. Break at Marcus Nanotechnology Building

3:40-4:25 (8 talks total)

Session M 5 Marcus Nanotechnology Building (4 talks)

Moderator: Trevor Thornton

3:40 p.m. Yoichi Ogata NNIN iREG Site: The University of Texas at Austin

Synthesis of Silicon and Germanium Nanowires .. .. page 31

3:50 p.m. Nicholas Heugel NIN REU Site: Washington University in St. Louis

Aluminum Nanowire Fabrication for use in Polarization Filters .. .. page 32

4:00 p.m. Elizabeth Fullerton NNIN REU Site: The University of Texas at Austin

Utilizing Solution-Grown Silicon Nanowires in Photovoltaic Devices . .. . page 32

4:10 p.m. Won Jun Kuk NNIN REU Site: Howard University

Growth of Silicon, Silicon Carbide, and
Boron Nitride Nanowires for Electronic Applications .. .. page 33

Session B 5 Petit Biotechnology Building (4 talks)

Moderator: Lynn Rathbun

3:40 p.m. Matthew Kiok NNIN REU Site: Cornell University

Patterning Antigens with Near-Field Optics .. .. page 33

3:50 p.m. Brandon Piercy NNIN REU Site: Harvard University

Overcoming Cellular Breakdown in Hyperdoped Silicon Alloys . .. . page 34

4:00 p.m. Issa Beekun NNIN REU Site: University of California, Santa Barbara

Distributed Bragg Reflectors In Ultra Low Loss Silicon Nitride Waveguides .. . page 34

4:10 p.m. Jennifer Gilbertson NNIN REU Site: University of Washington

Synthesis of Self-Assembling Silver Nanoparticles
for Surface Enhanced Raman Spectroscopy .. .. page 35

4:20 p.m. Fellowship Programs, Dr. Lynn Rathbun

4:45 p.m. Adjourn

6:30-9:30 p.m. Evening Event at Marcus Nanotechnology Building

Viva Las Vegas

Friday, August 12, 2011

6:30-8:00 a.m. Breakfast for interns at hotel

8:30-8:40 a.m. Announcements

8:40-9:40 a.m. (12 talks total)

Session M 6 Marcus Nanotechnology Building (6 talks)

Moderator: Jim Marti

Session B 6 Petit Biotechnology Building (6 talks)

Moderator: Kathryn Hollar

9:40-10:00 a.m. **Break at Marcus Nanotechnology Building**

10:00-11:00 a.m. **Panel Session; Careers in Nanoscale Science and Engineering**

Presenters: *Dr. Pamela Bhatti, Georgia Institute of Technology; Dr. Swami Rajaraman, Axion Biosystems; Dr. Samantha Andrews, Georgia Institute of Technology*

11:00-11:20 a.m. **Break at Marcus Nanotechnology Building**

11:20-12:10 p.m. **(5 talks total)**

Session M 7 Marcus Nanotechnology Building (5 talks)

Moderator: Joyce Palmer

11:20 a.m. Jade M. Noble **NNIN REU Site: Cornell University**

Film Making in Digital 3D: Selective Area Atomic Layer Deposition . . . . page 41

11:30 a.m. Malena Agyemang **NNIN REU Site: Georgia Institute of Technology**

Characterization of 2-300 nm Al_2O_3 Films Deposited via ALD . . . . page 42

11:40 a.m. Kelly Suralik **NNIN REU Site: Stanford University**

Tribology of Atomic Layer Deposition Films . . . . page 42

11:50 a.m. Matthew Diasio **NNIN REU Site: University of Michigan, Ann Arbor**

Electrodeposition of Metals onto Aligned Carbon Nanotube Microstructures . . page 43

12:00 p.m. Julia Podmayer **NNIN REU Site: University of Washington**

Stability of Zwitterionic-Modified Au Nanoparticles in Complex Media: Effect of Surface Packing Densities . . . . page 43

12:10-1:00 p.m. **Lunch at Marcus Nanotechnology Building**

1:10-1:50 p.m. Panel Session on the NNIN iREU Program, Marcus Nanotechnology Building

Presenters: *2011 NNIN iREU Interns: Clara Chow, Zachary Connell, Brian Benton, Mark Brunson, Brian Chung, and Kevin Chen. Summer Research at Forschungszentrum Juelich, Germany*

1:40-1:55 p.m. Poster set up at Marcus Nanotechnology Building

1:55-4:25 p.m. 2011 NNIN REU Poster Session

1:55-3:10 p.m. Posters A-L
3:10-4:25 p.m. Posters M-Z

4:30 Adjourn

6:30-9:30 p.m. Evening Event; Game Room and BBQ at Student Recreation Center

Saturday, August 13, 2011

6:30-8:30 a.m. Breakfast for interns at hotel

9:00-9:10 a.m. Announcements

9:10-10:10 a.m. (6 talks total)

Session M 8 Marcus Nanotechnology Building (6 talks)

Moderator: Melanie-Claire Mallison

10:10-10:30 a.m. Break at Marcus Nanotechnology Building

10:30-11:20 a.m. (5 talks total)

Session M 9 Marcus Nanotechnology Building (5 talks)

Moderator: Tomoko Borsa

11:20 a.m.-1:00 p.m. Lunch and Photographs at Marcus Nanotechnology Building

1:00-2:00 p.m. (6 talks total)

Session M 10 Marcus Nanotechnology Building

Moderator: Domingo Ferrer

1:00 p.m. Lisa Anne Hendricks NNIN REU Site: University of Michigan, Ann Arbor
Characterization of AIN Thin Films for Application in Bulk Acoustic Filters .. . page 49

1:10 p.m. Daryl Vulis NNIN REU Site: Cornell University
Confinement Assisted Self-Organization of Photonic Templates .. .. page 50

1:20 p.m. Seyedshahin Ashrafzadeh NNIN REU Site: UCSB
Design and Characteristics of Multiple Quantum-Well Lasers .. .. page 50

1:30 p.m. Drew Schiltz NNIN REU Site: University of Colorado Boulder
Analog Lithography of Complex Phase Plates for Sub-Diffraction Lithography page 51

1:40 p.m. Gawain Lau NNIN REU Site: University of Colorado Boulder
Flexible and Stretchable Networks of Metals . .. . page 51

1:50 p.m. Yuki Matsuoka NNIN iREG Site: University of Michigan, Ann Arbor
Local and Global Effects on the Growth of Carbon Nanotube Micropillar Arrays page 52

2:00-2:15 p.m. Break at Marcus Nanotechnology Building

2:15-2:55 p.m. (5 talks total)

Session M 11 Marcus Nanotechnology Building (5 talks)

Moderator: Mack Carter

2:15 p.m. Leah Laux NNIN REU Site: University of Minnesota-Twin Cities
Neutrophil Chemotactic Response to Competing
Chemokine Gradients in a Microfluidic Device .. .. page 52

2:25 p.m. Francisco Pelaez, III NNIN REU Site: University of Minnesota-Twin Cities
DNA in Nanochannels .. .. page 53

2:35 p.m. Abigail Halim NNIN REU Site: Washington University in St. Louis
Self-Assembled Gold Nanoparticles for Biosensing Applications .. .. page 53

2:45 P.M. Seiya Suzuki NNIN iREG Site: University of Colorado Boulder
Graphene-Based Ultrafast Electro-Optical Modulators .. .. page 54

2:55 p.m. Max Li NNIN REU Site: Washington University in St. Louis
Gold Nanostructures with Tunable Photothermal
Properties for Cancer Treatment . .. . page 54

3:05-3:15 p.m. All Hands Wrap Up

3:15 p.m. Adjourn-Free Time

6:30-11:30 p.m. Evening Event at Marcus Nanotechnology Building

Movie Night; Win, Lose, and Draw; Carnival Food; Games

Sunday, August 14, 2011

Everyone departs!
Use MARTA to get to the airport

2011 NNIN iREU Abstracts

Dimensional Analysis of µL-Sized Microbial Fuel Cells

Nicole Hams
Biochemistry, University of Missouri – Columbia
NNIN REU Site: Arizona State University

NNIN REU Principal Investigator: Dr. Junseok Chae, Electrical Engineering, Arizona State University
NNIN REU Mentor: Dr. Seokheun Choi, Electrical Engineering, Arizona State University
Contact: njhyr8@mail.mizzou.edu, junseok.chae@asu.edu, shchoi2@asu.edu

A microbial fuel (MFC) is a bioelectrical device that uses a microbe to oxidize a substrate and captures the electrons that would normally continue through the microbes' electron transport chain. The captured electrons at the anode are conducted through load (resistor bank) and are reduced at the cathode to complete the bioelectrical circuit; this is how MFC converts chemical energy into electricity. With today's emerging drive towards a more sustainable energy source, macro-sized MFCs use biomass, such as sludge, to generate electricity from any bacteria present in the media. However, applicability of such technology remains low due to only generating power densities of 10 W/m^2. Such low power density cannot compete with power sources in macro size. In this research we aim to miniaturize macro-sized MFC by taking advantage of microelectromechanical systems (MEMS) technology. As a result, research interest is to studying a micro-sized MFC for portable power sources and to better understand variables in order to optimize power density. Our study monitors how dimensional parameters effects power density as well as directly comparing power density and columbic efficiency of a micro-sized and macro-sized fuel cell.

Using a MEMS Sensor Array to Map the Temperature of the Hot Springs in Yellowstone National Park

Karl Schliep
Chemistry and Mathematics, University of Minnesota Morris
NNIN REU Site: Arizona State University

NNIN REU Principal Investigator: Hongyu Yu, School of Electrical, Computer, and Energy Engineering, and School of Earth and Space Exploration, Arizona State University
NNIN REU Mentor: Jonathon Oiler, School of Earth and Space Exploration, Arizona State University
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A common problem for researchers at Yellowstone National Park (YNP) is measuring the temperature gradients across microbial transitions in the hot springs, which are strongly acidic or alkaline, and at high temperatures. Due to their size, commercial sensors used for scientific measurements have limited spatial resolutions preventing them from accurately measuring across millimeter scale boundaries. A solution to this problem is using microelectromechanical systems (MEMS) sensors. Our research focused on a MEMS thermistor array, which provided a spatial resolution of 5 mm, meaning measurements can be taken every 5 mm. Using MEMS fabrication techniques the arrays were fabricated as thermistors consisting of layered platinum on titanium and leads of copper. To protect the arrays from the harsh conditions of the hot springs they were coated with an inert biocompatible polymer, Paralene-C. A data acquisition card was used to record the temperature. The thermistor array was verified in the field at YNP measuring both depth gradients through sedimentary material and microbial mats within the hot springs and also surface gradients in the hot spring outflow channels between photosynthetic, chemosynthetic, and lifeless areas. Our results shed light on the interactions between the water temperature and the location of the different microbial communities living in the hot spring environment.

Devices for Investigating Electrical Transport in Topological Insulators

Joshua Mendez
Physics, Louisiana State University
NNIN REU Site: Cornell University

NNIN REU Principal Investigator: Daniel Ralph, Physics, Cornell University
NNIN REU Mentors: Alex Mellnik and Jennifer Grab, Physics, Cornell University
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Topological insulators are a recently discovered class of materials, which have a unique set of properties. These materials are electronically insulating in the bulk but have conducting states that exist only on their surface. Bismuth (III) telluride (Bi_2Te_3) and bismuth (III) selenide (Bi_2Se_3) are two examples of topological insulators that we have investigated here. We have attached leads to bismuth telluride nanostructures grown by solvothermal synthesis using aligned electron beam lithography. We are also fabricating gated Hall bar structures from bismuth selenide thin films, which were grown using molecular beam epitaxy by collaborators.

Measuring the Thermodynamic Properties of Water at Negative Pressures in Synthetic Trees

Zachary Sonner
Microelectronic Engineering, Rochester Institute of Technology
NNIN REU Site: Cornell University

NNIN REU Principal Investigator: Abraham D. Stroock, Chemical and Biomolecular Engineering, Cornell University
NNIN REU Mentor: I-Tzu Chen, Chemical and Biomolecular Engineering, Cornell University
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Liquids at negative pressures are observed in nature as a means for liquid to travel through the xylem of a plant or tree. The mechanism by which this occurs is similar to an osmotic process whereby liquid within the xylem is placed tension (negative pressure) and allows for the plant to remain hydrated in the presence of sub-saturated air and soil; allowing fluid to be "pulled" up the xylem. In this condition, the liquid is in a superheated, metastable state that is prone to boiling. The focus of this project is fabrication of a microfluidic device in silicon capable of holding water at negative pressures. Bulk silicon bonded to glass is used to form holding vessels for the liquid water with a semi-permeable porous silicon layer to couple to the outside environment. When subjected to reduced relative humidity, water vapor diffuses through the porous silicon membrane placing the contained water in tension. Potassium hydroxide (KOH) was used to create the holding vessels, an electrochemical hydrofluoric acid (HF) etch was used to create the porous silicon membrane and a borosilicate wafer was bonded to the silicon wafer backside to seal the devices. Currently, the largest issue in this process is with the predictability and stability of the porous silicon membrane.

The Micro-Fabrication of Composite Thermal Capacitors

Israel Ilufoye
Mechanical Engineering, University of Maryland Baltimore County
NNIN REU Site: Georgia Institute of Technology

NNIN REU Principal Investigator: Dr. Andrei Federov, Mechanical Engineering Georgia Institute of Technology
NNIN REU Mentor: Craig Green, Mechanical Engineering, Georgia Institute of Technology
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In order to maintain the rate of advancement achieved in traditional microprocessor technology over the past few decades, recent studies have focused on 3D stacked microprocessor architectures because of their potential computational advantages as well as a decrease in noise, power consumption, and reduction in parasitic capacitance. The implementation of this solution has been limited by the generation of transient hot-spots. To manage the thermal impact of these transient hot- spots, we fabricated composite thermal capacitors (CTC), which locally increase the thermal capacitance of the chips in the vicinity of the hotspots, allowing for longer device operating times. The fabricated and tested prototype devices consist of phase change materials (PCM), and heat spreader matrices monolithically integrated into silicon chips also containing micro-heaters, which simulate microprocessors. The CTC's novelty arises from its efficient coupling of high thermal conductivity materials with PCMs to yield enhanced thermal conductivity while retaining a desirable effective thermal capacitance. This project concentrates on the fabrication process using micro-fabrication techniques such as chemical vapor deposition, photolithography, metal deposition via electron beam evaporation and sputtering, and reactive ion etching. These techniques must be implemented while taking precautions to limit defects and contamination which may ultimately impair the effectiveness of the device.

Conformal CVD Copper Seed Layers for Silicon TSV Structures

Parker Clark
Electrical Engineering and Materials Science, Stanford University
NNIN REU Site: Harvard University

NNIN REU Principal Investigator: Dr. Roy Gordon, Chemistry, Harvard University
NNIN REU Mentor: Yeung (Billy) Au, Chemistry, Harvard University
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As the current 2D approach to integrated circuit design reaches its computing density threshold, chip designers are looking to three-dimensional transistor integration to increase computing performance. One roadblock to 3D integrated circuit development is the interconnection of planar device layers along the third dimension using through-silicon via (TSV) features. These vias must be filled with a highly-conductive material, such as copper, in order to connect stacked device layers without introducing undesirable resistances. Our proposed method employs an efficient CVD process to conformally coat high-aspect-ratio TSV structures with a copper seed layer so that the vias can subsequently be filled economically with electroplated copper. First, the TSV structures are coated with a thin (2-3 nm) layer of CVD manganese nitride, which serves as a copper diffusion barrier. The structures are then briefly (~ 30 s) exposed to iodide gas, which acts as a catalytic surfactant for copper growth through physisorption on the manganese nitride surface. A thicker (~ 100 nm) copper-manganese alloy is then deposited via CVD to conformally coat the vias. A final post-deposition anneal can be performed to enhance film adhesion by forming a manganese silicate layer at the substrate interface. By tuning growth parameters for this process, we successfully coated 20:1 TSV structures with a conformal copper seed layer for subsequent electroplating.

Surface Wettability Induced by Nanofilm on Titanium Surface and Osteoblastic Cell Morphology

Noelia Almodovar
Chemical Engineering, University of Puerto Rico
NNIN REU Site: Georgia Institute of Technology

NNIN REU Principal Investigator: Dr. Barbara Boyan, Biomedical Engineering, Georgia Institute of Technology
NNIN REU Mentor: Jung Hwa Park, Materials Science and Engineering, Georgia Institute of Technology
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The characteristics of titanium surface properties including roughness, chemistry, and wettability used in orthopedic and dental implant can directly influence cell morphology and cellular response at the interface between living tissue and implanted material surface. The aims of this project were to develop a coating method to control surface wettability without altering micron and submicron complicated surface roughness and to examine how surface wettability influences cell morphology in a time-dependent manner. All of the samples (sand-blasted/acid-etching, SLA, $S_a = 3.1\ \mu m$) were, firstly, oxygen plasma treated and then, each at different time points (0, 2, 6, 10, and 24 h), coated with chitosan. Surface wettability, chemistry, morphology, and roughness were characterized by using contact angle measurement, x-ray photoelectron microscopy, scanning electron microscopy (SEM), and confocal laser microscopy, respectively. A gradient in wettability was successfully controlled without modifying surface roughness. MG63 osteoblast-like cells were plated on surfaces with different wettability. After 1.5, 3, 6, 12, and 24h incubation, cells were fixed, dehydrated, and critical point dried. Cell morphology was examined by using SEM. SEM imaging demonstrated that during the initial cell-material interactions, cell shapes, whether they are elongated or rounded, depend on surface roughness and surface wettability.

Fabrication of Microfluidic Devices for Synthesis of Janus Particles

Brittany Alphonse
Biomedical Engineering, University of Rhode Island
NNIN REU Site: Georgia Institute of Technology

NNIN REU Principal Investigator: Todd Sulchek, Mechanical Engineering, Georgia Institute of Technology
NNIN REU Mentor: Kipp Schoenwald, Mechanical Engineering, Georgia Institute of Technology
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Microfluidic flow focusing devices (MFFD) are an easier, more accurate and repeatable way to create monodispersed Janus particles. Size, shape, and uniformity of droplets determine particle application, which is dependent on channel width. Decreases in channel width allows for more biological applications. The goal of this study was to fabricate an MFFD to synthesize Janus particles using a T-junction design with 50 μm width channels using three immiscible liquids. To do this, we designed a mask with the negative image of five of the same MFFD s to reduce cost, material waste, and increase repeatability. Quartz wafers were used due to lower etch rate, smoothness, and purity compared to other transparent materials. An adhesion layer was spun prior to S1827 photoresist to help the thin long channels adhere. Chromium was deposited 1 μm thick and etched to create the channels that were then fusion bonded to Pyrex® wafers. The transparent packaging allows for simple alignment, UV exposure of monomers and imaging of the process in real-time. Furrule connectors were adhered and tubing threaded in to allow for the flow of the immiscible liquids. A syringe was attached to the other side to control various flow rates. Ongoing studies will apply this design process to recreate MFFDs with 15 μm and 3 μm channel widths.

Evaluation of Modified Alumina Membrane for Bimolecular Separation

Tiffany Dunston
Biochemistry, Syracuse University
NNIN REU Site: Howard University

NNIN REU Principal Investigator: Dr. Kimberly Jones, Professor, Civil and Environmental Engineering, Howard University
NNIN REU Co-Principal Investigator: Dr. Malaisamy Ramamoorthy, Research Scientist, Civil and Environmental Engr., Howard University
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Membranes can be engineered to separate materials based on size, concentration, charge, temperature or other characteristic, which makes them versatile enough to be employed in various industries such as environmental engineering, chemical engineering, food processing, biomedical, among others. In biopharmaceutical and biomedical applications, membrane techniques replace other separation methods such as ELISA, western blotting, and polymerase chain reaction (PCR). The aim of this project was to modify large pore alumina membranes by coating with layers of collagen with the goal of developing a membrane with 90% solute rejection for biomolecules of different size fractions. The pore size of the modified membranes was determined by measuring the molecular weight cut off (MWCO). Porous alumina membrane supports modified with 1, 3, 6, and 9 layers of collagen by spin coating were employed, and 20 ppm of dextran solution of molecular weights 50, 80, 150, and 270 kDa were filtered individually through each membrane at 10 psi using a dead-end ultra filtration cell. A TOC analyzer was used to determine the concentration of the dextran in the permeate in terms of total organic carbon content of dextran by oxidation. The percentage rejection of each dextran was calculated and the molecular weight cut-off (MWCO) value for the membranes was derived from that value. The MWCO gave insight about the pore size, the function of the membrane, selectivity, and its ability to separate a particular molecule. Surface morphology was examined by SEM imaging to further confirm the magnitude of modification in addition to its effect on membrane pore size. The application of this project can be extended into micro fluidic devices and other medical applications.

Fabrication of a Novel Microfilter for Circulating Tumor Cell Enrichment and Culture

Julie Chang
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Detection of circulating tumor cells (CTCs) provides valuable information in diagnosis and prognosis of metastatic cancers, but the rarity of CTCs in blood makes it challenging to develop a method with sufficiently high sensitivity. Compared to traditional approaches, filtration of CTCs based on size has shown potential as a quick and inexpensive option. However, previous filter designs were mostly intended for fixed samples, preventing post-filtration live cell studies. This project presents a novel three-dimensional microfilter that is both efficient in viable capture of CTCs and relatively simple to fabricate. The device, resembling a basket, is a 10 μm layer of parylene patterned with small 4.5 μm gaps created by etching and 15 μm walls whose heights are defined by lithography. This design has the advantage that both the bottom and the walls of the "basket" will support the cells, distributing the stress on captured cells across a larger area and preventing cell rupture. Characterization confirms the structure of the device, and preliminary filtration with cultured tumor cells exhibits effective viable capture. Thus the process achieved successful fabrication of a microfilter that can be further evaluated for performance in enrichment of CTCs.

Nanomechanical Properties of Structured Biopolymer Networks

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Though the structural changes that occur during cell division are well known, the process by which nanoscale motor proteins cooperate in time and space to generate sufficient force for cell separation are not well understood. This study aims to characterize the mechanical forces that are generated during cell division on the length scale of a whole cell. This approach will give insight into the forces generated by the cytoskeleton during processes such as cytokinesis. By encapsulating dividing sea urchin embryos in a 3-D hydrogel matrix, the forces that a cell generates will be quantified using a modified form of traction force microscopy. To identify the optimal matrix material, bulk rheology, magnetic tweezers based microrheology, confocal microscopy, and cell viability tests were performed. Out of three potential matrix materials tested, a collagen based commercial hydrogel was found to be the most promising.

Design, Fabrication, and Testing of Hg/Au Microelectrodes for Sensing of Trace Metals in Oceanic Systems

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In electroanalytical chemistry, electrodes are used in potentiometry to detect trace amounts of an analyte in an aqueous system. Recently, the fabrication of microelectrode arrays by nanofabrication techniques has come into popularity for its ability to lower detection limits and provide increased selectivity. Inspired by Belmont et al. [1], a series of Au/Hg microelectrode arrays was designed as a working electrode in a potentiometric system for trace metal sensing in aquatic environments; these arrays tested the influence of electrode diameter, array size, and electrode spacing on signal detection. Arrays were designed using AutoCAD, while the physical electrodes were fabricated in a cleanroom environment using established nanofabrication methods. The conductive Au layer was patterned through photolithography and chemical etching. An insulation layer of Si_3N_4 was deposited using PECVD and patterned through reactive-ion etching. Since this is a novel method of fabricating microelectrodes, many tools had to be adjusted and characterized in order to create usable devices. After preliminary device fabrication, all electrode arrays will be taken to the Georgia Institute of Technology for mercuric electroplating and practical testing by our geochemistry collaborator.

References: [1] Belmont, C. et al. (1996). Anal. Chem. 329, 203-214.

Fabrication and Characterization of ZnO Nanowire Field Effect Transistors and ZnTe Nanosheet Field Effect Transistors

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Zinc oxide (ZnO) is a promising material for many nanodevice electrical applications due to its high carrier mobility and robust mechanical properties. The transparent nature of ZnO owing to its wide bandgap of 3.37 eV has stimulated investigation of transparent transistors on plastic substrates and optoelectronic devices. Zinc telluride (ZnTe) is a good direct bandgap material for optoelectronic devices because it is easily doped. Together, ZnO and ZnTe may theoretically form a P-N junction, allowing the fabrication of essential components such as light-emitting diodes. The first focus of the project is to fabricate ZnO transistors so that we can study the effects of low temperature fabrication processes on device performance. Low temperature oxides have been grown by remote plasma enhanced chemical vapor deposition and e-beam evaporation for comparison with devices on a thermal oxide gate insulator. The second focus has been fabricating ZnTe transistors so as to understand the electrical and optical properties of nanosheets with potentially useful two dimensional geometries. ZnTe nanosheet transistors have shown weak gate response and the photoconductivity of these nanosheets is currently being investigated. We hope to illuminate a useful comparison between one dimensional and two dimensional II-VI nanodevices.

The New Diamond Age: Hetroepitaxial Growth of Diamonds for Device Applications

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The objective of this research is to demonstrate the growth of diamond, through microwave plasma enhanced chemical vapor deposition (CVD), on non-diamond substrates (i.e. silicon, silicon-carbide, silicon coated with nickel, etc.). Diamonds grown by CVD have many characteristics that enable its use in medical, electronic and electro-optic applications. The substrates were coated with a diamond solution in an ultrasonic bath that created nucleation sites for diamond growth. With the specified parameters; 1100 watts, 50 torr, 400 sccm H_2, 1.6 sccm CH_4, layers grew at about 0.4 μm/hr. Diamond growth was confirmed using energy dispersive spectroscopy (EDS) due to the high levels of carbon on the substrates. Scanning electron microscope (SEM) images proved that diamond layers grew in various orientations based on the substrate it grew on. Silicon <100> grew high faceted and high quality layers with pyramidal, hexagonal, and cuboidal structures, while silicon <100> coated with nickel formed spherical shaped diamonds.

Ink-Jet Printing of Zinc Oxide-Based Semiconductor for Thin Film Transistors

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Ink-jet printing is widely used in arts and our daily lives. It consists of creating digital images by propelling droplets of ink onto a substrate. However, this technique can also be used to produce thin films electronics at a fairly low cost. Therefore, the objectives of this project are to develop ink-jet printed thin film transistors from zinc oxide-based solutions, and explore their morphological and electrical properties. Zinc oxide and zinc tin oxide precursors were directly printed onto a Si/SiO_2 substrate by controlling the substrate temperature and drop spacing. These variables have a strong effect on the geometric accuracy of the printed shapes, the film thickness, and its electrical performance. After printing, the samples were annealed to evaporate the solvent and from the semiconductor layer. Transistor I-V testing was done by landing source and drain probes directly onto the printed structure and using the Si substrate as a bottom gate. Devices showed a field effect electron mobility between 0.001 and 0.01 $cm^2V^{-1}s^{-1}$. Further work is needed to optimize the processing so that zinc oxide-based transistors can be applied in roll-to-roll processing of circuits with moderately good performance for large-area displays.

Shape-Specific FePt Nanocrystals for Spin-Transfer Torque in Magnetic Tunnel Junctions

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The high magnetocrystalline anisotropy, high chemical and thermal stability, and tunable morphology of FePt nanocrystals make them attractive for spin-torque transfer random access memory (STTRAM) applications. STTRAM at the bit level consists of a magnetic tunnel junction (MTJ) with ferromagnet / dielectric / ferromagnet top to bottom construction and operates on the principle of tunneling magnetoresistance (TMR). This project seeks to assess the viability of replacing the MTJ top ferromagnet layer with ferromagnetic FePt nanocrystals and to examine the effect of differing nanocrystal morphologies on the switching characteristics of the device. FePt nanocrystals were typically synthesized by simultaneous reduction of platinum acetylacetonate and thermal decomposition of iron pentacarbonyl. Oleylamine and oleic acid were used as surfactants. Nanocrystal morphology was controlled by varying solvents, sequence of surfactant addition, and reaction temperatures. The junction layers up to the dielectric were fabricated using a process which combined e-beam patterning, sputtering, and atomic layer deposition. The dielectric was then functionalized with poly(ethyleneimine) (PEI) to attach the nanocrystals. Bias dependence of differential resistance and tunneling magnetoresistance were also investigated on sputtered magnetic tunnel junctions including an ultrathin magnesium oxide tunnel barrier (~20Å) fabricated via ALD. Current induced magnetization switching was studied using pulsed measurements.

Optimization of Switching Layer for Tungsten Oxide Memristor Devices

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The memristor, e.g. a resistor with memory, has generated much interest as a newly accessible circuit component dependent on nanotechnology. A switching layer between two electrodes can change the resistance of the device by means of oxygen vacancy redistribution enabled by high electric fields. The film composition, specifically oxygen concentration gradient, thus has significant impact on device performance. The difference between a varistor and a memristor is the ability to remember a resistance when voltage is removed – the retention of the device. This project aims to fabricate memristors that demonstrate good resistance retention at a photolithography-compatible scale. Reactive sputtering was employed for the tungsten oxide switching layer, and the process was characterized using differing oxygen flow rates and substrate temperatures during sputtering, which can be fine-tuned to change the retention based on device application. It was determined through x-ray photoelectron spectroscopy that below 35% O_2 flow rate, samples became less stoichiometric, including therefore more oxygen vacancies. A flow rate around 25% was deemed best for controlled memristive effects. One application of memristors is as “synapses” in neuromorphic circuits: memristors’ ability to connect in large networks can be used to emulate neuron/synapse connections, and the memory component of the memristors simulates learning in the brain.

Microfluidic Protein Dialysis Device for X-Ray Scattering

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The purpose of the microfluidic protein dialysis device is to concentrate a protein solution to determine a protein’s structure by small-angle x-ray scattering (BioSAXS). The device allows users to create concentration series necessary for BioSAXS starting with a diluted sample, rather than diluting a pre-concentrated sample. This avoids potential irreversible accumulation of protein molecules in solution. The microfluidic device consists of five layers; the outermost layers are polymethyl methacrylate (PMMA) layers, followed by two layers of double-sided medical adhesive tape, separated by the innermost layer, a cellulose dialysis membrane. The Versalaser was used to carve channels, 1.00 mm wide and 0.05 mm deep, into each layer of medical adhesive tape. Lysozyme protein solution, a commonly used standard for testing structural biology, flowed in one channel, as a polyethylene glycol (PEG) solution flowed through the opposite channel. By the process of osmosis, water moved from the protein solution across the semipermeable membrane into the PEG solution, resulting in a concentrated protein solution. The microfluidic device was tested using a spectrophotometer to determine the absorbance of protein solutions at various protein solution flow rates and PEG flow rates. The results obtained thus far indicate the protein is concentrating, although further optimization is needed.

Development of Paper Accelerometers for Cheap Applications

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The purpose of this project was to explore the use of paper as a micro electro mechanical sensing device. A paper accelerometer was fabricated using a piezoresistive carbon ink and a conductive silver ink. Sensors were fabricated out of both bamboo and cellulose paper. The overall sensitivity of these micro electro mechanical (MEMS) devices is approximately 120 μN compared to a silicon accelerometer which is typically 80 μN. Silicon MEMS devices are more time consuming and expensive to produce. The paper MEMS are cheap and easy to fabricate, often in less than one hour. Such MEMS devices can be easily employed in less developed countries.

Fabrication of Dielectrics for Flexible Thin-Film Electronics

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Recent advances in organic semiconductor technology have paved the way for the development of all-organic transistor-based circuits that can be manufactured on thin flexible substrates. This opens up a variety of previously unrealisable application niches, such as flexible displays and sensor circuits for characteristics such as touch, pressure, temperature, and strain. It is desirable for all components of such circuits to be manufactured on the flexible substrate itself using the same processes, as this integration reduces the complexity of fabrication and the number of external components necessary for functional operation. In this work, a process for manufacturing a thin-film dielectric for use on polyimide substrate is explored, and a novel, fast method is presented for the micromachining of stencil masks for metal deposition, with minimum opening size of 20 μm. These processes enable the integration of capacitors and thin film transistors (TFTs) on the same substrate, as these devices are reliant on the availability of reliable dielectrics. Both n- and p-type transistors are fabricated, with the p-type transistors demonstrating saturation mobilities on the order of 1cm^2/(Vs), and the n-type transistors demonstrating saturation mobilities on the order of 0.1 cm^2/(Vs). These devices can therefore be readily integrated into flexible circuits, further enabling advances in relevant technologies.

Metallic Nanostructure for Surface Plasmon Resonance Biosensing

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Metallic nanostructures offer many applications in nanotechnology. Their optical, chemical, mechanical, and electrical properties enable, among other effects, the creation of surface plasmons. Utilizing these surface plasmon resonances, label-free optical sensing techniques with high sensitivity at the surface of the metal nanostructure are possible. With a multiplex imaging technique, the plasmons can provide detection specific to the area in which bio-molecules are located. This leads to more efficient and less costly biosensing. Furthermore, metal nanostructures are easy and cheap to produce using template stripping with reusable silicon molds. This can reduce current experimental costs by orders of magnitude, leading to the discovery of new drugs. This project covers fabrication of the metallic nanostructure sensing chips, realization of a surface plasmon resonance imaging system, and biosensing.

Measuring Height Mismatch and Phase Transition Temperatures of Model Lipid Bilayers

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Model lipid bilayers serve as a simplified means of studying many of the inter-molecular interactions that occur within cell membranes. For example, interactions between lipids and cholesterol can result in demixing of lipid bilayers into regions with different lipid compositions. This membrane phase separation can be observed in model lipid bilayers composed of a high-melting temperature (T_m) lipid, a low-T_m lipid, and cholesterol. The lipid structural factors that determine the phase separation temperature (miscibility temperature) of such a membrane are currently not well understood. Recent research has proposed that the miscibility temperature of lipids into liquid ordered (L_o) and liquid disordered (L_d) phases increases with the height mismatch of the two phases. The goal of our research is to elucidate the contribution of height mismatch vs. other lipid structural parameters in determining miscibility temperature. The purpose of this project is to discover whether two different membranes that have similar miscibility transition temperatures can possibly have dissimilar height mismatches between the demixed phases in their membranes. In this study, transition temperatures are determined by observing phase separation of giant unilamellar vesicles using fluorescence microscopy, and height mismatch is measured by atomic force microscopy (AFM) of supported lipid bilayers.

Synthesis of Few Layer Graphene Films of Large Lateral Dimensions

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Graphene is a substance of great interest to many in the scientific and technological communities due to its various unique applications in those fields. While methods to create graphene are constantly being discovered and improved, the challenge of making graphene in large lateral dimensions of the same high quality as small mechanically exfoliated flakes still remains unresolved. Although graphene can currently be produced in numerous commercial machines, these machines are quite costly. On the other hand, less expensive and self assembled machines are an attractive alternative. Members of our group assembled a thermal chemical vapor deposition (CVD) system to create this material in high quality and large lateral dimensions for commercial use by incorporating cost effective and new design measures. This paper shows how a non-commercial machine can be designed to overcome shortcomings in commercial-off-the-shelf (COTS) machines while also being more cost effective.

Optical and Electron Beam Patterning for Graphene Nanoribbon Devices

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Transistor scaling has allowed the microelectronics industry to advance over the last forty years, leading to denser, higher performance systems that consume much less power. However, silicon scaling has reached fundamental limits and a replacement material that can be scaled more is needed, leading to further performance improvements. Graphene is a monolayer sheet of graphite that has been shown to have very high mobility, potentially allowing for smaller, high-performance field effect transistors. However, in order use graphene for transistors, it must be sliced into nanoribbons about 5 nm wide to induce a band gap (due to quantum confinement). This width is beyond the patterning ability of traditional lithography, thus novel lithographic techniques must be developed. The research herein focuses on block copolymers (BCPs) as a mask for etching graphene nanoribbons (GNRs). The research performed focuses on fabrication of guiding structures for the alignment of straight, parallel BCP patterns. The effect of the depth of optically patterned guiding structures on BCP alignment has been investigated and several unexpected behaviors have been observed. Electron beam lithography has also been used to pattern guiding structures to determine how the narrower-width guiding structures will affect the BCP alignment.

Measuring van der Waals Forces in Graphene

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Graphene, a single atomic layer of graphite, is one of science's newest materials, being the strongest, stiffest, and thinnest substance on earth. Understanding of graphene improves everyday as researchers work to discover its mechanical and electrical properties, including its ability to conduct electrons better than any other material at room temperature. The focus of this project is to suspend thin layers of graphene over annular rings to test how the graphene interacts with the substrate in connection with a nanomechanical switch. Van der Waals forces, weak dipole-dipole bonds, adhere the graphene to the substrate. Through pressurization, the graphene can be disconnected from the center island of the annular ring and the attractive van der Waals forces can then be observed as the graphene is pulled back to the center island. This relates to a switch as the graphene can be released and reattached to the annular ring island multiple times. Positive photoresist lithography and mechanical exfoliation of graphene were employed to obtain suspended graphene over annular rings. Rings with suspended graphene both attached and not attached to the annular ring island were observed from a tapping atomic force microscope.

Electronic Graphene Devices Through Tip-Based Nanofabrication

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The purpose of this project is to explore the electrical properties of graphene. Our device is fabricated by coating silicon with a 400 nm layer of low stress nitride; the backside of the nitride is patterned and etched so that the silicon layer can be completely etched by KOH to form nitride membranes on the front of the device. A 150 nm bi-layer of Au/Cr electrodes is deposited onto the front of the device to form a four-point probe measurement system. Graphene is transferred on top of the device, so that its piezoresistivity can be measured by bonding wires to the metal electrode pads and actuating the device by piezo actuators (PZT). The piezoresistivity tensor elements of graphene can be extracted by putting the 4-point probes on each side of the membrane. The elements are tensor because the piezoresistivity might be different in different directions due to graphene samples' lack of directional uniformity. Using an interferometer the vibration profile, modes, and amplitude can be measured as well. With this knowledge, graphene could be applied to microelectromechanical systems (MEMS) for smaller and more sensitive devices.

Characterization of Optical Devices using a Pigtailed Fiber

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The hope of achieving integrated optical devices on-chip has to deal with how to couple light from off-chip sources into the optical devices. The coupling efficiency between off-chip fibers and on-chip waveguides is the subject of investigation in this project. We design a small acrylic plastic base holder to permanently hold the optical chip and two optical fibers with room curing epoxy, enabling fiber-waveguide coupling at very high efficiency. The optical chip has waveguides with SU-8 polymer core and silicon dioxide cladding fabricated using photolithography and plasma enhanced chemical vapor deposition (PECVD). To minimize loss, the facets of the waveguide are polished using aluminum oxide polishing paper with grits sizes down to 50 nm. The waveguide and fibers are aligned using two XYZ stages with submicron-precision controls. The alignment is done before and after application of the epoxy in order to adjust for any micron-level displacements of the fibers. The coupling efficiency for the pigtailed device is measured using a cutback method.

Soft Lithographic Fabrication of Bar Chart Phantoms for Axial Resolution Measurements in Optical Coherence Tomography

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Optical coherence tomography (OCT) is a growing technology that enables non-invasive 3D imaging of biological materials based upon reflection of light within a sample. As a relatively new technology, convenient methods for characterizing OCT systems, such as measuring resolution, are needed. Many optical imaging technologies use the US Air Force (USAF) 1951 bar chart as a standard calibration phantom for determining lateral resolution; however, this chart cannot be used to determine axial resolution due to feature positioning and the reflectivity of its chrome surface. In this project, we created a variation on the USAF 1951 bar chart with features that lie in the axial rather than lateral plane. We used photolithography in the nanofabrication lab to create a master template, and this master was used in the creation of PDMS phantoms with soft lithography techniques. PDMS was used for this phantom because it is less reflective than the standard chrome and allows light penetration to multiple features at various depths. Using the OCT systems in lab, we then determined the advantages and limitations of the phantom through comparison with other accepted characterization methods. A variation on this phantom may provide a convenient method for measuring axial resolution in OCT systems.

Flexible Membrane Liquid Lens

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Reconfigurable optical devices are important for optical system characterization, materials measurements, communications, and imaging. In particular, variable focus lenses have potential in many adaptive optical systems. In this project, a lens whose focus could be varied by fluid pressure was designed, fabricated, and characterized. The lens consisted of an aluminum, liquid-filled cavity that is sealed with a flexible polydimethylsiloxane (PDMS) membrane on one side and glass on the other. Pressure changes in the liquid-filled cavity cause the membrane to curve inwards or outwards, resulting in lensing. The goal of this project was the fabrication of a lens that maximizes focal length variability while minimizing aberrations. Several liquid lenses have been fabricated and have demonstrated focal length variability from 20 mm to 90 mm. Current work focuses on optimization of design to increase possible focal lengths and minimize aberrations.

Novel Optical Waveguides for High-Sensitivity Biosensing in Point-of-Care Applications

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Zero-mode waveguides are arrays of sub-wavelength apertures in a metal film which allows for the observation of single-molecule interactions at micromolar concentrations through the excitation of fluorescently tagged molecules. Zero-mode waveguides have many biological applications, such as allowing the real-time observations of the interactions between RNA polymerase and DNA during the process of transcription. While such waveguides can be currently fabricated by utilizing electron-beam lithography, this is both expensive and time-consuming. Thus, an alternative method of fabrication has been devised which is both cheaper and more efficient using conventional photolithography, lift-off, and electrodeposition. Negative resist is utilized in this technique, and various parameters were tested and characterized to determine the optimum conditions for better controllability and uniformity. The goal of this project is to utilize this innovative method of fabrication to create waveguides in the range of 50 nm in diameter and test the effectiveness of the fabricated waveguides in biosensing. Testing of fabricated wave-guides in diffusion experiments suggest detection of single-molecules.

Sol-Gel Route for Ultra-High-Quality Optical Resonators

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On-chip microlasers have potential applications in optical communication and in single particle/molecule detection. A microlaser requires three fundamental components: a high-quality microresonator, a gain medium, and a pump source. Our group uses silica microtoroids as resonators. To include gain medium, silica is prepared using the sol-gel process, during which the gain medium is introduced. The quality of the resultant microlaser depends on the quality of the gain-medium-doped silica sol-gel film. This study is concerned with the optimization of the sol-gel process to produce high-quality microresonators and use them for microlasing.

Sol-gel film quality is affected by factors including ingredient ratio, acidity, aging, and annealing temperature. This study examines the effects of temperature and aging. Sol-gel solutions were created and aged for different time periods. The prepared films were then annealed for 3 hours at 800°C, 900°C, 1000°C, and 1100°C. Film quality was analyzed using SEM and AFM, to detect porosity. Porosity should be avoided; it decreases the silica film refractive index, which reduces microresonator quality. For solutions aged above 36 hours, higher annealing temperatures resulted in less porous silica films. For fresh solutions, little to no porosity was detected, regardless of temperature. To obtain best results, silica films should be prepared from fresh solutions and annealed at higher temperatures.

Engineering Multifunctional Nanoparticles with Dual Modality Imaging Capabilities

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Multifunctional nanoparticles (MNPs) with dual modality imaging capabilities are of interest because they can be used to deliver multiple optical imaging agents to targeted locations for use with various instruments. Within this study, we tested two possible methods to engineer a dual modality nanoparticle system: a microemulsion system with encapsulation of MNPs and indocyanine green (ICG) dyes, and direct conjugation of near infrared (NIR) dyes to magnetic nanoparticles. Using the microemulsion system, we were able to form nanoparticles with an even distribution of encapsulated MNPs and an ICG encapsulation rate of 8-12%. However, we also observed aggregation and size variance from 200-400 nm in diameter among nanoparticles. When the surfactant was modified to allow targeting capabilities, discrete nanoparticles no longer formed. Extensive aggregation was also observed in the directly conjugated nanoparticles, and the dye did not crosslink to the MNP. Work with several different surfactants and conjugation methods to allow targeting and reduce aggregation in both systems is currently underway.

The Calibration of Optical Particle Sizer by Wafer Surface Scanner

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An optical particle sizer (OPS) is typically calibrated using polysterene latex (PSL) spheres and an electrometer, or similar instruments. However, these current calibration methods require high particle concentrations. Our project designed a low-concentration calibration method with micrometer-sized PSL particles for the OPS. By depositing a controlled number of particles on the wafer surface, we can calibrate the OPS based on the wafer surface scanner's (WSS) analysis of the deposited particles. In this experiment, we used a settling chamber for deposition. Residue particles were a primary problem. A long differential mobility analyzer (DMA) and a virtual impactor were included to decrease residue particles and increase the 3 μm particle concentration into the targeted range of 10-100 #/L. We also tested for background residue particles and the application of an electric field in the deposition chamber. Our best trial obtained 70%-80% 3 μm particle deposition. Future work will explore residue particle sources, WSS accuracy, DMA effectiveness, and flow rate control.

Fabrication and Testing of Voltage-Tunable Plasmonic Metamaterials in Mid-Infrared

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The device introduced in this work realizes the prospect of voltage-tunable frequency-selective surfaces in mid-infrared spectral range. Our devices consist of an array of sub-wavelength plasmonic elements fabricated on top of a semiconductor layer consisting of n-doped GaAs/$Al_{0.8}Ga_{0.2}As$ coupled-quantum-well heterostructures. The resonances of the plasmonic elements are tuned by changing the refractive index in the semiconductor layer. The intersubband transitions in coupled quantum wells occur at mid-infrared wavelengths, and are voltage tunable through the Stark shift. By the Kramers-Kronig relation, this translates to a large change in the refractive index of the semiconductor layer for transverse-magnetic-polarized light, thus providing the necessary mechanism for a tunable dielectric environment. The plasmonic absorber consists of an array of subwavelength crosses patterned within a 40 nm thick gold layer. These were designed through numerical computer simulations to absorb at the same frequency as the coupled quantum wells, thus allowing for maximal tuning of the plasmonic resonance. The plasmonic structures were fabricated using electron beam lithography and characterized using Fourier-Transform-Infrared-Spectrometer-based reflection measurements.

Nanoscale Diamond Lenses for Atomic-Scale Sensing

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Nitrogen-vacancy centers in diamond have demonstrated a number of useful room-temperature properties for applications in quantum information processing and magnetic sensing. The spin state of these defects can be optically initialized, manipulated using on-chip microwave fields, and optically read-out due to a spin-dependent contrast in photoluminescence. Because of diamond's high index of refraction, conventional optics collect only a fraction of the emitted photons. Solid immersion lenses can drastically increase this collection efficiency, allowing for faster measurements and opportunities for new experiments such as "single shot" read-out. In this work, we discuss progress made in the fabrication of solid immersion lenses on the surface of diamond substrates using two techniques: focused ion beam milling and photoresist reflow. The shapes of the lenses made with both techniques were characterized and optimized, and their effect on increasing the collection efficiency of nitrogen-vacancy center photoluminescence was studied.

Integrated Silicon Nitride Waveguides: Optimization of Fabrication

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Integrated waveguides enable the use of photons for transfer of data in a manner similar to that of electrons in integrated circuits. Examples of possible photonic devices range from on-chip spectrometers, opto-fluidic devices, and wavelength converters, to next generation optical communication links in computers. With an optimized fabrication process, a wider range of high performance devices can be developed. This project utilizes the existing silicon oxide mask silicon nitride plasma etch process with CHF_3 and O_2 which is known to produce passivating polymers that aid in etching straight sidewalls. It was seen in Blain et al.'s paper [1] that the addition of nitrogen into a similar plasma etch chemistry increases the silicon nitride selectivity by creating nitrogen-based gaseous products which are subsequently removed, so N_2 is added into the etch chemistry. Varying the parameters of CHF_3, O_2, and N_2 flow rates in addition to the bias voltage and pressure in multiple DOEs (Design of Experiment), and then measuring the resultant etch rate, selectivity, and sidewall angles allows for the creation of an etching process optimized for the Oxford 100. The current results enable the fabrication of 90 degree sidewalls with a selectivity of roughly 2 to 1.

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Piezoelectric Micromechanical Vibration Energy Harvester

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This research project focuses on design and fabrication of a piezoelectric micromechanical vibration energy harvester to power wireless sensor nodes. Typically, energy harvesters have maximum efficiency at a certain frequency. However, external vibrations such as walking or automotive vibrations occur at many different frequencies. Therefore, it is desirable to have a device that operates over a wide range of frequencies. The proposed energy harvester, which can be fabricated by standard microelectromechanical systems (MEMs) processes, converts mechanical energy to electrical energy using a piezoelectric thin film. We report on the fabrication process for the device with AlN-on-SOI structure.

Using Electron Beam Lithography for Nanowires Transistor Fabrication

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The objective of this project was to fabricate a nanowire transistor using electron beam lithography. Nanowire transistors are devices made to solve the scaling problem that contemporary silicon transistors have begun to face. By placing nanowires on the surface of silicon chips as opposed to using conventional photolithographic processes to create gates, the gate length restriction imposed on conventional methods can be overcome. To start this process a 60-100 nm SiO_2 layer was grown by dry thermal oxidation on a boron-doped, 0.005 Ω-cm resistivity, <100> silicon wafer. A layer of Cr/Au (10nm/100nm) was then evaporated onto the backside of the Si wafer and tested for ohmic behavior. Photolithography was then performed to create Cr/Au (10nm/100nm) fingers and pads on the top oxide layer. Nanowires were then deposited on the top surface by brushing with cloth followed by e-beam resist deposition. SEM was performed to locate the nanowires relative to the fingers and holes were developed in the resist and coated with Cr/Au (10nm/20nm) to attach the nanowires to the fingers. Devices were then tested.

Surface Characterization of Etched Micro- and Nano-Structures in Silicon for Phonon Heat Transport

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Careful control of heat flow at the micro-scale is crucial to many applications in energy systems. In insulators, heat is carried by excited vibrational states (phonons) with wavelengths from a few nanometers to several hundred nanometers. As device dimensions become comparable to these wavelengths, surface reflection becomes the primary scattering effect. We are studying thermal transport though etched silicon nanosheets. Their surface roughness must be quantified for a better understanding of heat flow. The atomic force microscope (AFM) is the best tool to resolve surface topography at the nanoscale. However, the tool lacks the capability to image vertical or near-vertical surfaces. The focus of this project is to develop and test a method to characterize both horizontal and vertical surfaces. We have investigated three possible techniques for sidewall measurement: 1) break nanosheets using nanoprobes and lay them flat for AFM inspection; 2) incline the device at an angle while measuring with the AFM; or 3) cleave the device near a nanosheet and mount it vertically in the AFM. While Method 2 has the benefit of being non-destructive, Method 3 appears to give the most reliable data. We have used these methods to characterize sidewalls created by several etch processes.

Patterning of the Metal Induced Crystallization of Amorphous Silicon

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Silicon wire photovoltaics (PVs) are a promising technology to answer the demand for cleaner and more cost-efficient energy source alternatives. A Si <111> oriented layer is required to grow the vertically aligned wires necessary to produce silicon wire PVs and aluminum induced crystallization (AIC) is one method to achieve a Si <111> substrate. Since AIC also produces crystal orientations other than <111>, the objective of this project is to maximize the percentage of Si <111> grains to promote vertical wire growth. We developed a process for fabricating patterned areas of Si/Al layers on a quartz substrate for AIC through pre-patterning, by lift off, and depositing the layers with e-beam evaporation or sputtering. Scanning electron microscope imaging showed that on patterned areas there was continuous crystallization with no evidence of a double layer which can inhibit vertical wire growth. We also concluded that exposing the aluminum layer to oxygen plasma for periods greater than 2.5 minutes before depositing the silicon achieved the same results as air oxidation of the aluminum layer for 24 hours. In the future, orientation imaging microscopy results would be necessary to verify the orientation of the silicon grains and the effect of patterning on microwire growth should be explored.

Adhesion and Cohesion Testing of Square Solar Cells in Inert Environments

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A thorough understanding of environmental effects on adhesion and cohesion within solar cells is necessary for continuing improvements in their efficiency and longevity. A novel technique for adhesion and cohesion testing of square solar cells is developed to eliminate contamination caused by sample preparation in current methods. Sample preparation is simplified by placing the load pins at the corner of the solar cell. The formula to obtain the energy release rate, G, for this configuration is derived. Using this modified double cantilever beam approach, we can prepare and test samples in controlled environments. Validation of methodology for testing of encapsulated solar cells in controlled environments is obtained using a proportional-integral-derivative (PID) feedback control system.

Synthesis of Silicon and Germanium Nanowires

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Crystalline silicon (Si) and germanium (Ge) nanowires were grown in toluene heated and pressurized above its critical point. Colloidal gold nanocrystals were used to seed nanowire growth by the supercritical fluid-liquid-solid (SFLS) mechanism with monophenylsilane (MPS) and diphenylgermane (DPG) as reactants. Using a growth temperature of 490°C, the simultaneous addition of MPS and DPG to the reactor led to the formation of distinct Si and Ge nanowires, as opposed to a $Si_{(1-x)}Ge_x$ alloy. The nanowire product was characterized using a range of methods, including x-ray diffraction (XRD), transmission electron microscopy (TEM), scanning electron microscopy (SEM) and nanobeam energy dispersive spectroscopy (EDS) mapping. The optical properties of the nanowires, including the reflectivity and absorption, were also measured using an integrating sphere.

Aluminum Nanowire Fabrication for use in Polarization Filters

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Polarization is a property of light that humans are incapable of seeing but contains holds a plethora of information. Material properties, shape, and surface properties can be determined from polarization, even if the image is hidden in a shadow. To take polarization images with a camera a polarization filter on the nano scale must be used. One type of filter is composed of aluminum nanowires. Aluminum and silicon dioxide are thermally evaporated onto a glass slide and then coated with poly(methyl methacrylate) (PMMA). Electron beam lithography is used to selectively weaken the bonds in the PMMA to create the filter pattern. Then the PMMA is developed to remove the weakened portions and exposing the silicon dioxide underneath. The sample is placed in a reactive ion etch chamber where it is bombarded with plasma to selectively etch through the SiO_2 and the aluminum. A scanning electron microscope was used to check the features of the nanowires.

Utilizing Solution-Grown Silicon Nanowires in Photovoltaic Devices

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Photovoltaic (PV) devices were fabricated using solution-grown silicon nanowires and phenyl-C61-butyric acid methyl ester (PCBM). Silicon nanowires were first synthesized, in relatively large quantities, using the supercritical fluid-liquid-solid (SFLS) approach. Gold nanocrystals acted as the catalyst seed, while monophenylsilane (MPS) was used as the Si precursor for nanowire growth. Devices were fabricated on glass substrates by mimicking a typical bulk heterojunction PV device: a back contact of Aluminum, an active layer of Si nanowires and PCBM, Poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS) as the hole-transport layer, and a top contact of indium tin oxide (ITO). Utilizing this method, functioning solar cells have been produced. The photovoltaic power conversion efficiency that has been achieved to date has been quite low, only 0.002%. Several approaches to improve the device power conversion efficiency were explored, including: varying the weight ratio between the Si nanowires and PCBM, etching and redispersing the Si nanowires in various solutions prior to deposition, alternative deposition methods like spin coating and drop-casting, as well as chemical etching of the nanowire surface prior to device fabrication.

Growth of Silicon, Silicon Carbide, and Boron Nitride Nanowires for Electronic Applications

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The objective of this project was to explore the growth of silicon, silicon carbide and boron nitride nanowires for electronic device applications. Nanowires hold a lot of promise for applications to the next generation of electronics because they are nanosized semiconductors that can be used to create extremely powerful and versatile circuits. These nanowires have been chosen because they all have excellent mechanical, optical and electrical properties. Silicon is known to have interesting effects on the nanoscale, such as the thermoelectric effects, and therefore can be used to increase efficiency by converting waste heat back into electrical energy. Silicon carbide and boron nitride nanowires are well known for their high mechanical strength, and therefore can be applied to harsh environments. In this project, we have grown silicon and silicon carbide wires with a diameter less than a hundred nanometers. Experiments on the boron nitride nanowires have not produced any results yet. The wires were grown in a horizontal chemical vapor deposition system using silane, propane, ammonia and diborane at 200 torr, with temperatures ranging from 800 to 1100°C. These wires were grown on silicon substrates using fifty to hundred angstrom of aluminum, gold, iron and cobalt as the catalyst.

Patterning Antigens with Near-Field Optics

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The membrane of a cell is constantly flowing sea of lipids stacked together in a bilayer. Gaining a better understanding of the diffusion of lipids across the surface can be achieved by modeling with supported lipid bilayers (SLBs) that have incorporated UV polymerizable and fluorescent lipids. The goal of this project is to fabricate planar, microscale patterned substrates for creation of SLBs that will be observed with optical fluorescence techniques. Fused silica wafers were patterned by contact lithography, etched by reactive ion etching, coated with a thin film of aluminum by a metal evaporator, and processed by wet chemical liftoff, resulting in a smooth surface with aluminum lying flush with the glass surface. A SLB will be constructed on the surface and the diffusion coefficient calculated by fluorescence recovery after photobleaching (FRAP). Future developments include improving the smoothness of the glass substrate, promoting SLB formation with polymerizable lipids, and working with patterns at the nanoscale. After optimization, these techniques can be applied to observe fluorescently tagged antigen-antibody-receptor complexes on the membrane surface and to better understand the cell membrane signaling cascade process.

Overcoming Cellular Breakdown in Hyperdoped Silicon Alloys

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A novel semiconductor processing technique called hyperdoping has the potential to improve solar cell efficiencies with minimal additional cost. One approach to hyperdoping consists of implanting an extremely high concentration of impurities into a semiconductor, damaging the surface layer, then using a rapid, high-energy laser pulse to restore the crystallinity of the material while retaining the impurities. However, this technique is limited by "cellular breakdown" in the host material: a failure of the solidification process characterized by "cells" of pure silicon surrounded by impurity-laden walls. By increasing the solidification velocity, it should be possible to retain a high impurity concentration and avoid cellular breakdown. Use of a Nd:YAG laser with a three-nanosecond pulse – a tenfold increase in speed over the XeCl excimer laser previously used – has enabled an analysis of the effect of solidification velocity on cellular breakdown in this method of hyperdoping. Cellular breakdown still occurs for ~ 1 at% iron in silicon, but may be mitigated for ~ 3 at% sulfur in silicon. Simulations suggest that reduced implant depth and laser energy may improve the surface solidification velocity and breakdown resistance.

Distributed Bragg Reflectors In Ultra Low Loss Silicon Nitride Waveguides

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Distributed Bragg reflectors (DBRs) are used extensively in the standard operation of semiconductor lasers. Such gratings have the ability to reflect select wavelengths of photons as a means to produce laser feedback. DBRs can be effectively used to tune a source into a zero order mode. An efficient grating requires precise fabrication techniques in addition to correct operation. The focus of this project is to fabricate grating structures with a silicon dioxide (SiO_2) cladding and a silicon nitride (Si_3N_4) waveguide and to use these structures to tune a source beam to emit light at a specified output. The first part of the project was to successfully fabricate the grating couplers using electron beam lithography (EBL) and a series of dry etch processing. The second part of this project was to test the fabricated grating by coupling light into the waveguide containing a single DBR and detecting the spectral response of the light emitted at the output. By this method fundamental grating parameters are inferred to aid in future laser design.

Synthesis of Self-Assembling Silver Nanoparticles for Surface Enhanced Raman Spectroscopy

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Research in metallic nanoparticles has become a topic of great interest due to potential applications across a diverse range of fields including photonics, nano-electronics and catalysis. Silver nanoparticles in particular have especial interest due to their unique optical properties. There are several possible methods to synthesize silver nanoparticles. However, silver nanoparticles have a tendency to aggregate and to oxidize. Moreover, synthesis routes are more difficult to control due to their strong dependence on reaction parameters. On the other hand, these particles show stronger plasmonic effects when compared to gold due to increased absorption and light scattering. The focus of this project is to create a standardized and reproducible synthesis route for monodisperse silver amphiphilic nanoparticles that will self-assemble into stable clusters with controllable geometry. Silver nanoparticles are synthesized and coated with varying amount of mono-functional polyethylene glycol chains (PEG) followed by octanethiol. This initiates particle self-assembly into clusters with varying geometries. The clusters are analyzed by small angle x-ray scattering (SAXS), UV/Visible spectroscopy, dynamic light scattering (DLS), and transmission electron microscopy (TEM). These silver nanoparticle clusters will be used in surface enhanced Raman spectroscopy (SERS) to enhance Raman scattering of specific analytes.

Examining Researcher Views on the Perceived Influence of Funding Sources and Conflicts of Interest in Nanotechnology Research

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Scholars have increasingly focused on the influence of funding sources on research directions and potential conflicts of interest (COI) that arise in scientific research today. Conflicts of interest occur when an individual has a stake in the outcome of a behavior, along with the means to influence the particular outcome, and may directly be influenced by funding arrangements. Understanding researcher perceptions of these issues and identifying opportunities for discussion and training are an essential part of this inquiry. Building on an initial study of nanotechnology industry and academic researcher views of funding sources and COI, the present study explores the extent to which graduate students, as the next generation of researchers helping shape the direction of the field, recognize and evaluate COI that arise in their work. The study included the implementation of a web survey among users of the 14 National Nanotechnology Infrastructure Network (NNIN) sites, gauging the extent to which researchers believe funding arrangements influence research directions. The survey instrument also measures the perceived influence of financial conflicts of interest on issues of scientific integrity and public trust.

The Ethical, Legal and Societal Implications of Nanotechnology

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Nanotechnology is expected to contribute to the solution of important challenges of the 21st century through advances in medicine (Roco 2003) and the environment (Theron 2007). In conflict with this promise is the fact that studies on the ethical, legal and societal impact of this technology are still very limited. This report compares how three countries — the United States, the Netherlands, and China — are approaching research and regulation of this new science. This comparison includes whether or not countries have applied the *Precautionary Principle*, which opposes using a "lack of full scientific certainty…as a reason for postponing cost-effective measures to prevent environmental degradation," to emergent technologies (Rio Declaration 1992). The role that the *Precautionary Principle* played in the electronics industry in the 1980s is used as parallel to the way the nanotechnology industry is regulated today. This report looks at past examples because history shapes a culture and creates different standards for what is or is not ethical. Other important comparisons include how legislation, education of the public, and safety of nanomaterials are addressed by each country.

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Biosensing Based on Surface-Enhanced Raman Scattering (SERS)

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Raman scattering involves the inelastic scattering of a photon from a sample in which the incident photon transfers energy to a molecule and is emitted at a different frequency. This change in energy allows for a spectroscopic technique that provides a molecular fingerprint of a sample. However, Raman scattering is only a small fraction of the light that is scattered from a molecule. Noble metal nanoparticles or nanostructures can greatly enhance Raman scattering to the orders of 10^6-10^{14}-fold due to the localized surface plasmon resonance, i.e., the so-called surface-enhanced Raman scattering (SERS). SERS is an effective technique for detection and distinction of biological samples. Using specially tailored substrates with quasi-3D gold nanostructures developed by Dr. Yu's group at the University of Washington, the Raman spectra of numerous biological species were enhanced greatly. SERS was first used to confirm that two different strains of the bacteria *Vibrio parahaemolyticus* could be identified and distinguished in a mixed sample by comparing to the SERS barcoding of each strain. Additionally, the optimal concentration of bacteria to obtain high reproducibility and intensity was determined. Furthermore, SERS was employed to detect chemicals spiked in whole milk to explore its capability of being used for direct detection of chemical contaminates in complex media.

Growth and Characterization of Aluminum Nitride Nanowires

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Nanowires are at the forefront of advancement in electronics because of their versatile and cost effective applications. Aluminum nitride (AlN) nanowires have many interesting properties in comparison to other wide-band gap III-V nitride semiconductors. They have a comparatively high thermal conductivity at low temperatures and a high resistivity along with the largest piezoelectric coefficient. AlN nanowires are therefore very attractive for use in electromechanical and optoelectronic devices. In our work, a horizontal chemical vapor deposition (CVD) system employing ammonia and aluminum chloride as the sources of nitrogen and aluminum respectively was used. We used substrates of silicon and coated some with thin layers of various metals as catalysts. The growth of AlN wires without a catalyst allows for dense growth and supports an aligned growth pattern. Growth temperatures ranged between 1000-1100°C with pressures of 100 torr and flow rates between 100-500 sccm. At these specifications AlN nanowires have not been grown. However a film of AlN has been observed on silicon samples and nickel coated silicon. During the process, under certain conditions, nanospheres of aluminum oxynitride have been observed via energy-dispersive x-ray spectroscopy (EDS), and successfully reproduced.

Deterministic Assembly of Alternative Materials onto Silicon Substrates

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Deterministic assembly of III-V compound semiconductor devices offers the promise of enabling innovative functions that go beyond the conventional use of digital electronics. Recent studies have achieved controlled placement of metal and semiconductor nanowires via electric-field-assisted assembly techniques. However, many III-V optoelectronic and electronic devices that are interest are considerably larger in size. In this project, we have studied the electric-field assisted assembly of 100 nm thick chromium (Cr) microtiles having widths of 1.2 μm, 2.4 μm, and 3.0 μm. The nonuniform electric field used to manipulate the microtiles was induced in the isopropanol (IPA) solution that suspended the tiles by applying an 100 kHz, 20 Vp-p bias voltage to pairs of interdigitated metal electrodes patterned on a silicon nitride coated silicon (Si) substrate. The electrodes pairs are separated by 3 μm and 5 μm wide gaps, and were coated with a 1 μm thick photoresist layer. The results of the study showed that uniformly spaced arrays of all of the microtiles could be assembled using this technique. The space between adjacent tiles in the array depended on the width of the tile and the gap. These promising results provide a proof-of-concept for the assembly of III-V epitaxial device layers on Si substrates.

Electrical Properties of the Ge/Si Interface

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Germanium-on-silicon (Si/Ge) photodetectors show great promise for use in high-power phonics applications due to their high bandwidth, low cost, and compatibility with silicon-based electronics. The performance of such devices is limited by defects that occur at the interface between the two materials. Silicon and germanium crystals have a 4% lattice mismatch, which results in the creation of traps, or energy states other than the valence and conduction bands, which carriers can inhabit. The focus of this project was to test devices in order to better understand the role these interface defects play in device performance. To characterize the devices two methods were used: (a) measurement of open-circuit voltage (V_{oc}) as a function of temperature to determine the potential barrier across the diode's p-n junction, and (b) measurement of the transient decay of an electrical signal under open and short circuit conditions to determine the minority carrier lifetime in the device.

Synthesis of Poly(Amino Ether) Capped Gold Nanoparticles for Transgene Delivery

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Poly(amino ether) capped gold nanoparticles represent an attractive solution to the high demand for non-viral gene delivery vectors. The polymer takes advantage of gold's unique surface functionalization by encapsulating the colloidal nanoparticle and, thereby, enhancing its stability and preventing its aggregation in biologically relevant media. Our research focuses on the synthesis and characterization of this unique class of nanomaterials. Several methods were employed to better understand their attributes and potential for biomedical applications, such as gene therapeutics. UV-vis and infrared spectroscopy was utilized to examine the particles' kinetics of formation, illustrating the rate at which nanospheres were being fabricated. Further spectra readings revealed good stability of the agents when dispersed in serum free media, indicating potential for biological applications. Zeta potential measurements further verified the stability of the polymer coated colloidal systems. The results suggested successfully capped gold nanoparticles and an unlikelihood of aggregation. Dynamic light scattering (DLS) readings confirmed the nanometric size of our particles, and gel electrophoresis investigated the binding of our polymer capped gold nanoparticles to enhanced green fluorescent protein (EGFP) plasmid DNA. Cytotoxicity experiments were conducted with prostate cancer cells (PC3) to investigate the optimal optical density for transgene delivery. Our research concluded with a preliminary, qualitative analysis of in vitro EGFP transfection.

Development of Fluorescent Based Quantification Method to Determine the Amount of Glycans Immobilized on a Surface

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The current method for quantifying the amount of glycan immobilized on a surface involves connecting a fluorescent linker to the carbohydrate and measuring the fluorescent intensity after surface modification to validate immobilization. However, the chemical moeity which the carbohydrate is attached drastically alters the binding affinity of carbohydrate binding proteins. The purpose of this project is to address this issue. Instead of linking a large fluorophore to the glycan, a smaller, less intrusive linker will be attached to the glycan; this linker will be used to attach the glycan to the surface. The surface reaction is a substitution reaction in which a fluorescent moiety (dansyl chloride) is substituted for the modified glycan. First, amine modified microbeads were functionalized with Dansyl Chloride. A substitution reaction was then performed with Alexa Fluor 594, an azide modified fluorophore. Green fluorescence, from the dansyl group, was shown to decrease, and red fluorescence, from the Alexa Fluor 594, increased over the course of the reaction. The next step of the project was to run a substitution reaction using an azide modified glycan and use the change in gross mean fluorescence intensity to quantify the amount of carbohydrate immobilized on the surface. Fluorescent microscopy and Thermo XPS were used to observe the surface modifications.

Multiplexed Silicon Nanophotonic Biosensing via Immobilized Protein Glycoconjugates

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Cell surface interactions are responsible for a myriad of cellular functions, including cell signaling, cell growth, morphology and host-pathogen interactions. Many of these processes are mediated by cell surface carbohydrates and glycoconjugates—including glycolipids, glycoproteins and extracellular polysaccharides. In particular, carbohydrates frequently act as receptors in the biochemical mechanisms involved in intercellular communication. The study of the glycans involved in the interactions between biological targets of interest thus has profound implications in terms of biosensing. More specifically, glycans can be used as selective capture agents of biological analytes, including proteins, cells and pathogens. However, despite their potential for biosensor applications, carbohydrates as biological receptors have been widely understudied due to the difficulty of accessing complex glycans. Modern biosensing techniques rely both on biological interactions of target analyte and receptors as well as sensor platform design. This project focuses on the integration of glycan receptors with silicon nanophotonic biosensors through the development of an optimized (i.e. low cost and time) protein-carbohydrate conjugation and immobilization scheme. Protein-carbohydrate conjugates were used to present glycans of biological interest on silicon photonic platforms for the purpose of biosensing. Both disaccharide-protein and tetrasaccharide-protein conjugates were employed to validate the bioconjugation strategy, and bioactivity was confirmed by the binding of relevant lectins such as ricin and concanavalin A. Finally, we demonstrated facile immobilization of oligosaccharide-protein conjugates for the specific and multiplexed detection of lectin analytes in solution using an integrated silicon nanophotonics biosensing platform.

pH-Sensitive Dendrimer Nanoparticles for Targeted Intracellular Imaging

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The high detection sensitivity of optical contrast agents in the near-infrared range enables noninvasive imaging of molecular conditions and processes. In particular, optical probes can be functionalized to target the molecular signatures of cancer cells in order to image tumors. Reducing background fluorescence would improve the contrast between normal and pathogenic tissue. We report progress on a novel dendrimer nanoparticle with pH-sensitive fluorescence activation in the lysosomes of cancer cells for improved tumor imaging with reduced background fluorescence in normal tissue. Polyamidoamine (PAMAM) dendrimers are tree-like polymer nanoparticles with tunable pharmacokinetics and multifunctionality. Many recent studies report the design and synthesis of novel dendrimer carriers and scaffolds with imaging, targeting, and therapeutic moieties. It has been demonstrated that PAMAM dendrimers are delivered to acidic lysosomes after cell internalization. Functionalization of the dendrimer with a pH-sensitive fluorescent dye yields an imaging probe that activates after cell internalization and trafficking to the acidic lysosome. Surface modification decreases nonspecific binding to normal cells, and conjugation to a targeting peptide delivers the probe to tumor tissue. Thus, fluorescence background is reduced in normal tissue.

Measurement of Platelet Clot Volume in Microscale Thrombosis Screening Device

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Cardiovascular disease (CVD) is the leading cause of death in the United States. In patients with CVD, local constrictions known as stenoses increase shear rates within arteries, causing platelets to form clots. This process, known as thrombosis, can result in the occlusion of the artery or vein and result in stroke or heart attack. We have developed an in vitro microfluidic device to measure thrombosis under stenosed flow. Clot formation within the stenoses is monitored until occlusion using simultaneous mass flow and light transmission measurements. To calibrate these light transmission measurements to clot volumes, we require measurement of the volumes independently. In this research effort, an estimate of the thrombus volume was calculated by using a combination of bright field and laser scanning confocal microscope (LSCM) images. First, bright field images were collected to calculate the cross-sectional area of the platelet clot. Next, LSCM images were used to determine the clot's internal density. These two methods were then combined to calculate volume by multiplying by the known height of the region and scaling by the density. The volume was around 3.0×10^7 μm^3 or 55% of the stenosis region.

Three-Dimensional, Label-Free, Photoacoustic Microscopy of the Tumor Microenvironment *In Vivo*

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Angiogenesis is a hallmark of cancer. Monitoring tumor angiogenesis is important to understanding the tumor microenvironment and developing new means to treat cancer. Photoacoustic microscopy has been proven powerful for three dimensional imaging of blood vessels with capillary resolution using hemoglobin as the endogenous contrast. Here, we propose that photoacoustic microscopy can be used for imaging of the tumor microenvironment in vivo and quantification of key parameters of tumor growth. The imaging system was first calibrated for the measurement of absolute total hemoglobin concentration using lysed bovine blood. Then, the system was calibrated for the measurement of absolute absorption coefficient using different dyes. As a demonstration, a U87 glioblastoma tumor was longitudinally imaged for three weeks. From the serial volumetric images of the tumor vasculature, several parameters associated with tumor microenvironment- the tumor volume, volume and tortuosity of tumor vasculature, and total hemoglobin concentration of blood-were extracted by imaging processing. The results show that, within three weeks, the tumor has grown to a size of 0.72 cm^3 with a vascular volume of 0.03 cm^3. The vessel tortuosity has increased by 25% compared with the baseline. In summary, photoacoustic microscopy has been demonstrated to be a good tool for imaging the tumor microenvironment.

Film Making in Digital 3D: Selective Area Atomic Layer Deposition

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When making electronic devices, two dimensional (2D) thin films can be created using atomic layer deposition (ALD). Although the resulting thin films are highly uniform and conformal, they are not useful in their 2D state. These films must be patterned using photolithography and etching to make viable 3D devices such as transistors. Copper is a common interconnect between transistors. However, it diffuses easily into silicon dioxide (SiO_2) and other dielectric materials. Tantalum nitride is deposited onto the dielectric before the copper interconnects are placed to prevent diffusion. Subsequent layers of TaN may be placed after the copper is laid to cover the dielectric and allow for another layer. If possible, it would be ideal for tantalum to grow on the dielectric but not on the copper. The ability to selectively deposit materials can be useful as it eliminates the intermediate steps such as photolithography. Selectivity may be achieved by manipulating the differences in the chemistries (such as the number of nucleation sites) of two unique substrates. This may allow for growth of a thin film on one substrate and not on the other. Tantalum nitride was deposited on both SiO_2 and copper using ALD to determine if selective growth can be achieved. TaN growth was analyzed using ellipsometry and atomic force microscopy.

Characterization of 2-300 nm Al_2O_3 Films Deposited via ALD

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Thin films are used widely across the engineering field, as electrical semiconductors, optical coatings, in drug delivery systems and in solar cells. Alumina thin films are the most ideal type of films due to their properties. They are hard and stiff, have good chemical and thermal stability, firm adhesion to many surfaces, a high dielectric constant as well as excellent insulating properties. However, even though these thin films are used frequently, the properties of the thinnest films are assumed to behave the same way as thicker films. The objective of this research is to characterize alumina thin films to give accurate measurements of the electrical properties at the nano-scale. Alumina thin films were deposited on silicon wafers via atomic layer deposition (ALD) at thicknesses ranging from 2-300 nm and ellipsometry was used to determine the films thickness. Then, electrodes of various diameters were deposited on the films and impedance measurements were carried out at different frequencies. From these measurements, resistance and capacitance values were derived as a function of film thickness and electrode size and compared to expected electrical properties. Results are found to depend heavily on the geometric parameters.

Tribology of Atomic Layer Deposition Films

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Atomic layer deposition (ALD) is revolutionizing the fabrication of nanoscale devices. ALD employs sequential, self-limiting vapor surface reactions and presents the ability to coat concavities and convexities of a surface uniformly with thin inorganic films. Since ALD films can deposit uniformly on a variety of materials with precise thickness control, they can tune surface properties independent of the substrate. For example, coatings can be uniquely hard or chemically stable, and the mechanical effects are dominated by surface qualities at the nanoscale. Thus, ALD can change the exhibited properties of a material greatly by depositing thin films. The electric properties of ALD films have been investigated extensively, yet the films' mechanical traits have not been well characterized. In this work, we investigate mechanical properties such as wear, adhesion and friction of the interface between ALD coatings. Custom micromachined silicon tips on compliant cantilevers are coated with various films using vapor and plasma ALD processes. A scanning electron microscope is used to observe tips before and after deposition. The coated tips are tested through laser Doppler vibrometry to monitor friction and adhesion. The knowledge of the mechanical effects of ALD films will improve our ability to fabricate nanoscale electromechanical systems.

Electrodeposition of Metals onto Aligned Carbon Nanotube Microstructures

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Nanocomposites offer a way to create materials with specific properties by ordering components on the nanometer scale. Carbon nanotubes (CNTs) are a particularly attractive choice for composite materials, due to their small diameter and outstanding mechanical and electrical properties. Previous studies on CNT-metal composites simultaneously deposited CNTs and the metal onto a substrate, resulting in materials with a low concentration of randomly oriented CNTs. We investigate electrodeposition directly onto vertically aligned CNTs as a means to realize nickel-CNT and copper-CNT composites, and attempt to optimize the procedure to result in uniform metal composite microstructures. The aligned nature of our structures could greatly enhance the composite's properties compared to randomly oriented CNT composites. Electrodeposition was performed at current densities ranging from approximately 2.5 to 500 mA/cm2, with deposition occurring consistently at densities above 25 mA/cm2 and composites becoming uniform above 100 mA/cm2. Morphologies range from isolated nanoparticles on CNTs at low current density and thick coatings at high current densities. Infiltration of metal to the interior of the CNT forest is observed under some conditions and is still under investigation. Future studies will characterize properties of the nickel composites for mechanical applications and the copper composites for electrical and thermal applications.

Stability of Zwitterionic-Modified Au Nanoparticles in Complex Media: Effect of Surface Packing Densities

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The advent of nanoparticles has lead to potential advances in modern biomedical technology. Prominent among these are the use of nanoparticles in drug delivery systems, diagnosis, and biosensing; however, many issues arise when introducing foreign bodies into *in vivo* environments, including aggregation, immune response, and nonspecific protein adsorption. For practical applications, it is important to modify the surface of nanoparticles to improve their biocompatibility and colloidal stability in complex media. Herein, the atom transfer radical polymerization (ATRP) reaction was employed for coating gold nanoparticles with a non-fouling poly(carboxybetaine) (pCB) shell. The size and surface packing density of the pCB shell was optimized through the ratio of reactants and the reaction time. The stability of nanoparticles with different packing densities was tested with Dynamic Light Scattering (DLS). Confocal laser scanning microscopy (CLSM) was further applied to gain some insight into the interaction between cells and nanoparticles. Samples containing different surface packing densities were tested to compare these cellular level interactions. It is expected (or will be ideal) to create pCB-coated nanoparticles with excellent stability and multi-functional property for targeted delivery and diagnostics.

Characterization of Floating-Gate Graphene

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Graphene is known for its high electron mobility (over 5,000 $cm^2V^{-1}s^{-1}$), however, because of its zero bandgap, graphene is a non-ideal semiconductor for switches. Theoretical and experimental results indicate that graphene nanoribbon (GNR) opens up a bandgap because of the quantum confinement effect (inversely proportional to the width). Therefore, it is crucial to control the width of the growth down to sub-10 nm with a reliable method. However, the line edge roughness (LER) from the e-beam or photolithography degenerate the quantum confinement, which hinders the further application of GNR. Thus, combining the controllable width and sharp edge is one of our technical goals. The spacer lithography, a state of art patterning technology, has been widely used in current industry to create sub-pitch smooth patterns such as FinFET (a nonplanar, double-gate transistor). We combine the e-beam lithography with well-calibrated spacer lithography to seek a better electrical performance on the metal-oxide semiconductor field-effect transistor (MOSFET) structure.

Graphene Resonators for Mass Sensing

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In mass sensing, detection is achieved via a shift in the resonant frequency of substrate. Graphene, with its atomic layer thickness, low mass, and unique electrical properties, is an ideal, sensitive substrate for mass sensing. In this project, graphene resonators are fabricated by suspending graphene over a keyhole and electrically contacting the graphene with platinum (Pt) electrodes. These devices can be both electrically and optically modulated, and are optically detected with interferometry. Applications include gas chromatography and detection of biological molecules.

Fabrication of Free-Standing Graphene Films for Probing the Intrinsic Ultrafast Electron Dynamics

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Graphene has exhibited extremely high carrier mobility (200,000 cm2V?1s?1), ultrafast carrier relaxation time (< 100 fs), and fast saturable absorption. However, substrates interact with graphene causing doping effects and lowering the carrier mobility. To mitigate the effects of substrate interactions, this project aims to fabricate free-standing graphene grown by chemical vapor deposition (CVD). Photolithographic techniques were used to pattern holes on 100 μm double-side polished silicon wafers. The holes (2-50 μm width) were selectively etched in the <100>-plane through the wafer with potassium hydroxide. In a separate process, CVD graphene was grown on a 25 μm copper foil catalyst. The graphene domain size was characterized via scanning electron microscope, revealing ~ 20-50 μm single-crystal domains, with an average size of ~ 30 μm. Poly(methyl methacrylate) (PMMA) was used to stabilize the graphene before etching the copper and transferring the graphene to the etched silicon wafer. The PMMA was removed by baking the sample in an H2/N2 gas atmosphere at 400°C. Free-standing graphene covering 10 μm holes has been observed and confirmed with Raman spectroscopy and shown to have an extremely small D-peak and high 2D/G-peak ratio, indicating pristine graphene. Currently, optical testing of saturable adsorption and carrier relaxation time is being performed as well as fabrication process optimization.

Growth and Characterization of Graphene for Use in Graphene Field Effect Transistors

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Graphene, an atomic layer allotrope of sp^2 bonded carbon, has gained the attention of the researchers in electronics and materials science. This is due to graphene's unique potential to enable high speed in future nanoelectronics, such as graphene field effect transistors (GFETs). The current challenge with moving forward in the creation of these devices is the inability to create large areas of low-defect graphene. The focus of this work was to investigate a reliable protocol to produce large area high-quality graphene for device application. Chemical vapor deposition (CVD) was employed to synthesize graphene on copper substrates. The processing gas used for growth was methane (CH_4). Certain variables of the CVD parameters were manipulated to optimize the recipe for obtaining best graphene film. Specifically, the amount time in which the substrate was exposed to the methane varied between 3 and 9 minutes. The amount of annealing time in conjunction with the flow rate of the annealing gas, hydrogen, was also varied from 3 to 10 minutes and 10 standard cubic centimeters per minute (sccm) to 1000 sccm. Raman spectroscopy was then used to determine the quality and thickness of the graphene, which is then subjected to transfer to a target substrate for device fabrication.

Development of Carbon Nanotube Field-Effect Transistors for Use in Next Generation Electronics

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Due to its exceptional electronic properties, the carbon nanotube field-effect transistor (CNTFET) is a promising alternative to the traditional metal-oxide-semiconductor field-effect transistor (MOSFET) used in current devices, of which further scaling down in the sub-22 nm range has faced serious limitations in the fabrication process as well as in performance capabilities. CNTFETs can overcome these limits by replacing the channel material in MOSFETs with thin carbon nanotubes with diameters of 1-2 nm. Because various difficulties have arisen in the mass production of reliable CNTFETs, this project aims to fabricate and analyze the efficiency of a number of these devices, examining the viability of their optimization for industrial applications. Spinning solutions that have been specifically sorted for a high concentration of primarily semiconducting carbon nanotubes onto silicon substrates, we then located these tubes on an Atomic Force Microscope (AFM). The devices were manufactured through e-beam lithography and deposition. We applied test voltages between the source and drain of these devices and observed the amount of current flowing through the channels with respect to the backgate voltage. Insights gained as a result of these experiments will have a significant impact on the performance and power of future electronic devices.

Time-Resolved Study of Anisotropic Nanostructure Growth using Integrated Droplet-Based Microfluidics and X-Ray Absorption Spectroscopy

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The objective of this project is to develop an integrated droplet-based microfluidic device, and study the structural evolution of nanomaterial generated within the device via x-ray absorption spectroscopy and high-energy x-ray scattering. Flow-focusing microfluidic devices enable the formation of droplets with volumes ranging from nL-pL at high frequencies (10-100 Hz). These droplets behave as well-mixed batch reactors in which nanoparticle-forming reactions take place. The high-frequency of droplet generation allows for large sampling sizes to determine the influence of system variables on the final nanostructure product. Our prototype microfluidic device was constructed out of polydimethylsiloxane (PDMS) using contact lithography, soft lithography, and plasma bonding to fabricate a PDMS microfluidic device bonded to a glass slide. We initially encountered instability when generating droplets due to the presence of filters that created pressure fluctuations in the channels. We then re-designed the device which allowed for consistent droplet formation at variable flow rates of the continuous and dispersed phase fluids at frequencies over 100 Hz. Currently we are incorporating resistive heaters and thermocouples onto the glass portion of the device for on-chip heating and temperature measurement. For future applications, the integrated device will be constructed entirely out of glass for *in-situ* x-ray analysis.

Fabrication of GaAsBi Heterojunction Bipolar Transistors

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III-V semiconductor based bipolar junction transistors are favored in high performance circuits because of their high amplification and low output impedance. Heterojunction Bipolar Transistors (HBTs), which utilize a junction of lattice matched semiconductors with different bandgap energies, excel in high frequency applications. The transistor gain depends exponentially on the discontinuity between the base and emitter band junction. This allows for higher doping in the base, lowering the output impedance and improving RF performance. Gallium arsenide bismuthide ($GaAs_{(1-x)}Bi_x$) is a novel material for HBTs. $GaAs_{(1-x)}Bi_x$ is lattice matched to GaAs and narrows the bandgap by ~ 90 meV/%Bi. The band discontinuity in $GaAs_{(1-x)}Bi_x$ is entirely in the valence band, preserving the electron mobility. The focus of the project is to fabricate the first $GaAs_{(1-x)}Bi_x$ HBT and characterize the material. A six-step fabrication process was developed incorporating optical lithography, wet and dry etching, annealing, PECVD nitride deposition, thermal evaporation, and lift-off. Epitaxially grown $GaAs_{(1-x)}Bi_x$ HBT devices with bismuth concentrations of x~2.3% were fabricated. The devices have a minimum emitter size of 12 μm, using a minimum feature size of 4 μm and 2 μm. $GaAs_{(1-x)}Bi_x$ sheet resistance, mobility, and gain were measured. Current-voltage characteristics were measured for the base-collector and base-emitter pn junction diodes and compared to homojunction GaAs data as well as simulated results.

Characterization of Ion Sensitive Field Effect Transistors (ISFETs) for Cellular Scale pH Measurement

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Commercially available ion-sensitive field effect transistors (ISFETs) are ideal for use as potential of hydrogen (pH) sensors in space- and material-limited applications such as lab on a chip devices. However, ISFET drift continues to be a major obstacle to precision and accuracy in ISFET measurements. Though it may not be possible to entirely eliminate drift in currently manufactured ISFETs, techniques have been developed which may aid in the prediction and minimization of its effects. In this work, a unique approach was used where relays were integrated into the ISFET control circuit in order to determine the effect of electric field change. Drift characterization was performed by varying the pH of the solution to which the five identical ISFETs were exposed and the frequency at which the relays were switched on and off. A correlation was found between the pH of the solution and the rate of drift. For one ISFET the average drift was found to be 1.09 nA/s for pH 12, 0.835 nA/s for pH 10, 0.373 nA/s for pH 7, and 0.273 nA/s for pH 4. Switching off was found to decrease drift in the subsequent "on" period. On average drift was found to decrease by 0.115 nA/s per unit change in pH.

A Microchannel-Scaffold Electrode Array for Peripheral Nerve Interfacing

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Peripheral nerves have limited regeneration ability after injury. Previously, studies have demonstrated that channels, with appropriate topographical cues, enhance nerve regeneration through extended gaps. Utilizing this, we are developing highly aligned microchannels that are further integrated with electrodes for nerve interfacing. By doing so, we can direct the axonal path of regeneration such that it passes over the electrodes to facilitate electrical recording and stimulation. The scaffold design presented here includes patterned gold electrodes with channel walls composed of a photoresist. The resulting structure is then rolled and inserted into polysulfone tubes to form a scaffold. Currently, *in vivo* studies in rats are being conducted to determine the optimal distance between adjacent microchannels. Additionally, we are pursuing *in vitro* studies utilizing a modified design for electrical testing of dorsal root ganglion to better understand axonal growth and signal recording. Lastly, the process for the final scaffold with integrated electrodes is being refined concurrently with fabrication of a preliminary structure on which we intend to pursue electrical testing. The scaffold and cell culture device will be crucial in attaining a new level of direct control in advanced prosthetic limbs through closed-loop mechanisms.

$PbZr_{0.52}Ti_{0.48}O_3$ Films with Reduced and Exaggerated Zr:Ti Gradients

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Lead zirconate titanate ($PbZr_{0.52}Ti_{0.48}O_3$, abbreviated PZT) thin films have shown great promise in many applications, including energy harvesting devices, computer memory, and miniaturized sensors and actuators, due to their piezoelectric and ferroelectric properties. Efforts to prepare PZT thin films via standard sol-gel deposition result in a compositional gradient, as a Ti-rich phase nucleates first. This compositional gradient is known to adversely affect the piezoelectric properties of the film. In this study, several PZT films were prepared with varying degrees of this compositional gradient, and the effect of the gradient on the electrical properties of the material is examined. The films were prepared using a standard sol-gel deposition process, a "gradient-free" sol-gel process introduced by Calame and Muralt, and a "gradient-enhanced" process, which is the inverse of the gradient-free process. The relative permittivity, piezoelectric coefficient $e_{31,f}$, capacitance, and loss are reported for each of these films. The gradient-free films show the best piezoelectric coefficient ($e_{31,f}$ = -11.4 C/m^2 on Si substrate), while the gradient-enhanced films show poor piezoelectric properties ($e_{31,f}$ = -7.5 C/m^2 on Si). These results confirm that the gradient-free process produces PZT films with superior piezoelectric properties.

Microfabricated Silicon Carbide Thermionic Energy Converters for Solar Energy Generation

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Microfabricated thermionic energy converters (TECs) could be a crucial candidate for concentrated solar thermal power plants. TECs convert heat directly to electricity. They can therefore be thought of as heat engines in which the working fluid is electrons themselves. Electrons are "boiled" off the hot cathode and then condensed and absorbed at the cooler anode: the temperature difference produces a voltage between the cathode and anode. Recent studies have shown that a combined photovoltaic and thermionic process, termed photon enhanced thermionic emission (PETE), could increase the efficiency of TECs. Thus far, only PETE emitters have been fabricated successfully of silicon carbide (SiC). This study explores the fabrication of SiC cathodes (emitters) with integrated SiC anodes, i.e., complete converter structures. The fabrication process involves wafer bonding, reactive ion etching to pattern the structures, and vapor HF releasing to suspend the cathodes (emitters). We have fabricated the devices with a 1.7 μm gap between the cathode and anode, with a yield of over 50%. Using resistive heating, we measured the thermionic current. Later, we will use laser heating to demonstrate the first micro fabricated TECs and measure the conversion efficiency to explore future use in clean energy production.

Characterization of AlN Thin Films for Application in Bulk Acoustic Filters

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The goal of this project was to optimize aluminum nitride (AlN) thin film properties for use in bulk acoustic filters. The Tegal AMS 2004 tool was used to sputter AlN films onto silicon wafers patterned with molybdenum electrodes with a titanium seed layer. Ideally, films should have near zero stress, highly oriented crystalline structure, and high uniformity. To optimize the film properties, three main parameters of the sputtering system were controlled: DC bias, argon gas flow, and nitrogen gas flow. DC bias affects uniformity while argon and nitrogen gas flow rates affect stress and crystal orientation A higher DC bias led to a more uniform film. By adjusting the DC bias, uniformities less than 1.9% were achieved. Increasing the gas flow rate results in an increase in the stress. Crystal orientation was characterized by the full width at half maximum (FWHM) of rocking curves from XRD measurements. The FWHM values were low, ranging from 1.25 to 1.54, suggesting good crystal orientation. Increasing the argon flow lowered the FWHM values while increasing the nitrogen flow rate raised the FWHM values. Once the conditions for the best quality films were determined, new filter devices were fabricated and their performance was characterized.

Confinement Assisted Self-Organization of Photonic Templates

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The self-assembly of spherical colloidal particles has been used to generate photonic templates for use in integrated optical devices; however, stronger light-matter interactions have been predicted for colloids with more complex geometries. Simulations have shown that large and robust photonic band gaps may be achieved by lowering the crystal symmetry using asymmetric scattering units [1]. Empirically verifying the bandgap properties of nonspherical two-dimensional (2D) monolayer and quasi-2D transition colloidal crystals has been limited by the lack of large area samples. This project focuses on growing large photonic templates with controllable phase through self-assembly by gravitational sedimentation in height-confined cells. Using 2.7 μm thick photoresist, we constructed wedge cells with a smaller minimum angle than previously achieved. Cells were able to promote the growth of colloidal crystals measuring several hundreds of micrometers from mushroom cap-shaped particle building blocks. The hexagonal and unconventional rotator and buckled phases were observed by confocal microscope and examined using image analysis. The structures were characterized using positional and orientational correlation functions as well as order parameters. A parallel plate confinement cell with a base filter is being developed as the next cell refinement to produce larger crystals by capturing a higher colloid concentration.

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Design and Characteristics of Multiple Quantum-Well Lasers

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With the exponential growth of internet users and data-hungry devices, the need for faster and more accessible communication has been on the rise. In this regard, vertical cavity surface emitting lasers (VCSELs) have the great potential to make such applications practical by their implementation in optical interconnect and data centers. However, there are resistive losses that reduce laser functionality. By studying the structure of VCSELs and comprehending the losses, we are able to fabricate and employ lower resistive VCSELs in order to reach higher modulation speeds. In this process, different components of VCSELs — multiple quantum-wells, separate confinement heterostructure, and distributed Bragg reflectors — were simulated and tested to characterize their properties and come up with a desirable design. The effects of different concentrations of materials, such as indium and aluminum, were observed using photoluminescence and transmission line measurements. Our simulations show that the resistivity of separate confinement heterostructures and distributed Bragg reflectors can be reduced by our design rules.

Analog Lithography of Complex Phase Plates for Sub-Diffraction Lithography

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Analog phase plates enable one to arbitrarily tailor the shape of a laser focus with lower loss than alternative methods such as computer-generated holograms. Applications of these shaped foci include sub-diffraction microscopy and lithography. Custom phase plates are fabricated using analog, maskless photolithography. The two phase plates fabricated are a half-wave step and a full-wave spiral, which generate first order Hermite-Gaussian modes and Gauss-Laguerre (doughnut) modes, respectively. This cheap and versatile process allows for the phase plates to be quickly designed and produced for any given wavelength. The phase plates are characterized with a Shack-Hartmann wavefront sensor, a profilometer, a scanning electron microscope (SEM) and other microscopic analysis techniques.

Flexible and Stretchable Networks of Metals

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Much interest exists in advancing the field of flexible electronics. Moving away from rigid, planar substrates opens up unique applications in various areas, including computing, sensing, and energy technology. The nanofabrication of flexible and stretchable networks of metals were pursued here as a novel material useful for flexible electronics. The project consisted of developing methods for the synthesis of nanostructured networks with periodicities of 50 nm and processes for the transfer of these materials to elastomeric substrates such as polydimethylsiloxane (PDMS). Block copolymers were used as a unique method of lithography, resulting in thermodynamically controlled self-assembled morphologies on a silicon wafer that would otherwise be difficult with other conventional top-down processes. Lamellar nanostructures of unique connectivity and thickness were fabricated using polymers of varying molecular weights and relative concentrations of polystyrene (PS) and poly(methyl methacrylate) (PMMA). The selective removal of the PMMA domains followed by metal deposition using thermal evaporation and liftoff processes enabled the production of metal networks that could subsequently be isolated and transferred to a flexible substrate. Characterization of the nanostructured networks by field-emission scanning electron microscopy and electrical tests prove the fabrication of connected metal networks over lateral distances greater than 50 μm.

Local and Global Effects on the Growth of Carbon Nanotube Micropillar Arrays

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Synthesis of micropatterns of vertically aligned carbon nanotubes (VA-CNTs) is studied in a hot wall chemical vapor deposition (CVD) tube furnace with C_2H_4 precursor gas on Al_2O_3-Fe catalyst. We investigate the effect of pattern density on the growth rate and straightness of high aspect ratio cylindrical CNT micropillars. To this end, we designed catalyst circle patterns having different diameters and spacings keeping a constant total catalyst area per substrate. We also designed patterns having sinusoidal spacings between circles to investigate local and non-symmetric pattern density effects. Our experiments show that the pillars can deflect towards (attractive) or away from (repulsive) one another and these two deflection regimes can occur on the same substrate on identical patterns. We hypothesize that the non-uniform growth rates among the patterns can be responsible for the pillars deflection. A simple theoretical model is formulated to quantitatively capture the effect of non-uniform growth rate on bending of individual pillars. The mechanism of the local attractive and repulsive geometry is still under investigation.

Neutrophil Chemotactic Response to Competing Chemokine Gradients in a Microfluidic Device

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Neutrophils play an important role in the immune system by both degrading foreign bacteria and releasing mediators that contribute to the inflammatory response. Chemokines released from an injury site create a gradient of signaling molecules that guides neutrophil movement towards the site. Multiple different chemokines may be released from the same site, resulting in a complex signal which must be interpreted by the neutrophil. The interactions between several prominent chemokines are unknown. In an effort to better understand how the presence of multiple chemokines affects chemotaxis, our group has fabricated a microfluidic device that allows us to expose neutrophils to a time-constant gradient of two chemokines and monitor chemotactic responses of neutrophils to the gradient. This will provide insight into which chemokines are most dominant and in what concentrations. Preliminary results suggest that gradients of fMLP affect neutrophil chemotaxis.

DNA in Nanochannels

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Deoxyribonucleic acid (DNA) is the building block of life and has been the key to understanding diseases and evolution. As a consequence, understanding fundamental properties about DNA is an important research topic. But the statistical properties of DNA changes when confined channels smaller than the radius of gyration of the DNA molecule. By making nanochannels of different sizes, we can understand the diffusive properties of DNA as a function of nanochannel size. Since DNA is a large polymer, we can use the correlations found in DNA to understand the properties of other much smaller polymers. Channels are masked by projection lithography and the silicon is etched using a plasma etcher. Since we are in the lower limit for channel width for projection lithography, ~ 500 nm, and the channels need to be about 200 nm or less, the channels are coated with silicon dioxide using plasma enhanced chemical vapor disposition (PECVD) to make than them narrower. By using PECVD, we can easily and cheaply make different size channels by just changing the amount of oxide deposited on the channels. Using *Escherichia coli (E. Coli*) cells that express long bacterial artificial chromosomes, ~ 289 kbp, we will grow these cells and extract the chromosomes so we place them in the nanochannels to observe their diffusive properties.

Self-Assembled Gold Nanoparticles for Biosensing Applications

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The time-varying electric field of electromagnetic radiation causes oscillation of conductive electrons of metal nanoparticles. The resonance condition, termed localized surface plasmon resonance (LSPR), falls into the visible regime for noble metals, such as gold, silver, and copper, and is extremely sensitive to changes in the composition of the nanoparticle environment. Moreover, the assembly of these nanoparticles generates a plasmonic coupling between adjacent particles, leading to significant sensitivity enhancement. Such a property makes nanoparticle assemblies an attractive platform for biosensing applications. This study presents a controlled, rapid process for self-assembly of gold nanoparticles (AuNP) using aminothiols and a method to transfer AuNP assemblies onto substrates, while preserving the assembly structure and optical properties. AuNP in solution were assembled using p-aminothiophenol (p-ATP) and transferred by immersion onto substrates functionalized with either polyelectrolyte multilayers of poly(allylamine hydrochloride)/poly(sodium 4-styrenesulfonate) or 3-aminopropyltriethoxysilane. The extent of self-assembly was manipulated by using different molar ratios of p-ATP/AuNP. Ultraviolet-visible and Raman spectroscopy and transmission and scanning electron microscopy results showed that these assembly and deposition techniques succeeded in transferring AuNP assemblies while retaining structure and properties. The use of these substrates for biosensing applications is being investigated.

Graphene-Based Ultrafast Electro-Optical Modulators

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The principle of self-feedback for graphene saturable absorbers allows for the creation of ultrafast graphene-based electro-optic modulators, which combine ultrafast passive saturable absorption with active electro-optic modulation capabilities. In this work we demonstrate such graphene-based electro-optical modulators in a reflective geometry, which employ electric-field gating for active control of Fermi levels in graphene. The modulator is based on a thin-film structure consisting of a Cu/Al top-electrode on transferred graphene prepared by chemical vapor deposition and a 185 nm-thick Ta_2O_5 dielectric layer on a reflective Al bottom electrode. The Ta_2O_5 film thickness was optimized to enhance the electric field of the 1.55 μm light at the location of the graphene. The control voltage was applied between top Cu and bottom Al electrodes. The modulation depth, measured at 1.55 μm wavelength was approximately 0.4% at an applied voltage of 1 volt. This high modulation was achieved at such a low gate voltage owing to the high-κ value of Ta_2O_5, and the local and enhancement of the electric field of 1.55 μm light.

Gold Nanostructures with Tunable Photothermal Properties for Cancer Treatment

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Gold nanoparticles have a variety of properties that make them favorable for photothermal treatment; however, several of these properties vary depending upon the shape or morphology of the nanoparticles in question. To that extent, we synthesized and investigated gold nanohexapods, a novel class of nanoparticles derived from gold octahedra. In our comparative study of gold nanohexapods, gold nanocages, and gold nanorods, nanohexapods showed comparable photothermal efficiency with the other two types of nanoparticles when tests were done with the nanoparticles in solution. Next, to promote the accumulation of nanoparticles in cancer cells and at tumor sites, and thus allow for *in vitro* and *in vivo* studies, poly(ethylene glycol) chains were attached to the nanostructures (PEGylation). Studies with melanoma cancer cells showed that the gold nanohexapods had the highest rate of uptake among the three types of nanoparticles—in addition, the PEGylated nanohexapods displayed no apparent cytotoxicity even at concentrations of up to 1 nM. *In vivo* studies with mice showed that 7-8% of the nanohexapods could accumulate in the tumor 12 hours after the nanohexapods had been intravenously injected. Detailed studies should be completed in the future to supplement these results, but gold nanohexapods appear to be a promising photothermal agent for cancer therapy.

Electrical Single Molecule Investigations by Means of Mechanical Break Junctions

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The mechanically controlled break junction (MCBJ) technique was utilized to investigate the conductance of single molecules. Octanedithiols have been extensively investigated in previous work and were measured as a check of our techniques and equipment. Dendrimer molecules with a ferrocene core (CSA-FcGluOH), were measured using these techniques for the first time. Further measurements were carried out with metal ion complexes to aid in the collection of data for a publication revision. In addition, we explored the complex kinetics and kinematics of a mechanical system involving humanoid polymer structures used to alternately facilitate and hinder the diffusion of a macro-scale polymer sphere.

Traveling in Europe was very accessible and a definite highlight of the summer. Germany alone is a great country to explore, especially cities like Berlin and Munich. We also traveled outside of Germany with trips to London, Paris, Prague, Amsterdam, and Brussels. My most unique experience was travelling to a small Trappist brewery in Belgium. We were able to get some of their beer that is only available at the monastery itself (and must be reserved in advance) and has been rated the top beer in the world. We were also able to see events like a Women's World Cup soccer match, the Tour de France, and Wimbledon.

Investigation of Electron Transport in Functionalized Carbon Nanotubes

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Carbon nanotubes are being functionalized with Mn_4 clusters specifically designed to replace surface carboxylate groups. A series of quantum transport measurements will be carried out to understand the electronic coupling of these single-molecule magnets to the nanotube. The nanotubes are grown using a chemical vapor deposition process. Individual nanotubes are contacted with palladium contacts using electron beam lithography. The first step in this research is to prepare the dilution refrigerator for these measurements by optimizing its measurement equipment. Electrical measurements were carried out on nanotubes at a base temperature of 70 mK to observe the Coulomb blockade and determine the electron temperature. Future work involves functionalizing the nanotubes and performing characterization and transport measurements.

While performing the research in Jülich, Germany, I was able to experience life in a European research institution and travel around the continent. Forschungzentrum Jülich is one of the premier research centers in Europe. Yet it can have a slower pace than institutions in the United States. Coffee breaks and foosball breaks are common throughout the day. My travels brought me to Berlin, Munich, Amsterdam, Prague, Paris, Brussels, and the European Organization for Nuclear Research (CERN), among others. Even though travel is mostly restricted to weekends, getting a taste of various parts of Europe was a fantastic experience.

Manipulation of Graphene Bubbles on Hexagonal Boron Nitride Substate

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Graphene, a single atomic sheet of carbon atoms, is known to have superior electrical, thermal and mechanical properties. Because of these advantageous qualities, graphene is currently being used in a variety of applications and must undergo various fabrication processes. In one such process, where mechanically exfoliated graphene is transferred from PMMA to a hexagonal boron nitride substrate, the formation of large bubbles between the substrate and the graphene sheet has been observed. The aim of this project is to further explore the properties of these bubbles and gain an understanding of what may be trapped inside as well as insight as to the adhesion properties of graphene. This is done by observing changes in the volume of the bubble as well as changes in the attraction force of the graphene in response to an applied gate voltage.

This project was part of the NNIN iREU Program at TU Delft in the Netherlands. While the research itself was exciting, the overall experience of living and working in an international setting is what I enjoyed the most. During the weekdays I enjoyed interacting with the people in my lab, who were from all over the world, and on weekends I was able to travel and experience new cultures.

Characterization of Embryonic Rat Cortical Cells Grown on Printed Protein Patterns

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Microcontact printing (μCP) provides a simple, reproducible method of creating a defined pattern on various substrates for the purpose of studying neuronal cell growth. A protein mixture was stamped onto substrates (generally silanized glass) in a specific pattern. Cells are plated and allowed to grow for one, two, or three days. The growth of the axon and dendrites are controlled by the pattern and were visualized by immunostaining. Single-cell polymerase chain reaction (PCR) was used to analyze changes in gene regulation caused by the protein pattern. Additionally, the effects of a solution of 1,3,7-trimethyl-1*H*-purine-2,6(3*H*,7*H*)-dione, β-D-galactopyranosyl-(1→4)-D-glucose, and lactoglobulin and casein proteins at various concentrations and for multiple dosings were studied for affect on neuronal behavior.

Every weekend, we had the opportunity to travel to different parts of Europe. I traveled to Brussels, Berlin, Poperinge (*A Quest for the World' Best Beer*), London, Prague, Munich, Amsterdam, Paris, Dublin, and Rome. The trips took us to the Eiffel Tour, Prague Castle, and the Berlin Wall, among many other places, and gave us the opportunity to shoot a crossbow, go to Wimbledon, see a part of the Tour de France, go to a Women's World Cup soccer game, and adventure to Poperinge.

Capacitance Measurements of Single Indium Arsenide Nanowires

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Indium arsenide nanowires grown in a molecular beam epitaxy (MBE) system are processed into field effect transistors (FETs) with a wrap around gate configuration for capacitance measurements in order to be able to directly determine the carrier concentration and mobility of the wires. Nanowires with different doping levels of silicon are used to explore the effect of dopants on the carrier concentration and mobility. The test structure in which the transistors are processed is designed to reduce and cancel out any parasitic capacitances which are typically orders of magnitude above the actual capacitance values of individual nanowires so the correct capacitance values can be extracted.

We tried to make the most out of our time in Europe and ended up traveling just about every weekend. The railway system is amazing and we were able to get just about everywhere except for London, which we went to by air, with our Eurail passes. Jülich, the town where the research center, is at is a bit out of the way, but still only an hour away from major cities such as Cologne or Aachen which have routes to just about anywhere and which also are fun places to go themselves.

Defect Analysis of Molecular Monolayers with Electrochemistry

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Self-assembled monolayers are an inexpensive and versatile method to alter surface wetability and to detect molecules in biosensors. Self-assembled monolayers of oligopeptides were electrically characterized in drop electrode experiments. Due to the high variance in results, the monolayers were further studied via cyclic voltammetry. Peptide monolayers, comprised of chains of alanine or aspartic acid and terminating with cysteine, were found to contain defects and pinholes of various sizes. These pinholes were discovered by changing the electrolyte strength, thereby changing the effective diameter of the redox molecules. Redox molecules larger than the pinhole diameter were blocked by the monolayer and could not exchange electrons with the underlying Au substrate. The effects of Au substrate roughness, peptide length, pH, and potential induced desorption on monolayer formation were also analyzed for the peptide monolayers.

Characterization of YBCO Superconducting Thin Films for Antidot Structure Applications

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The use of superconducting materials for thin film oxides has recently sparked interest in a new field of engineering research called "Fluxonics," named after the physical quantization of magnetic flux lines that occurs in such materials when a threshold current has been injected. Structures consisting of patterned indentations, termed Antidots, have been fabricated using standard UV lithography methods on high-temperature Type II superconductors such as yttrium-barium-copper-oxide (YBCO) to structurally guide and support magnetic flux vortices. Various growing and processing conditions concerning film qualities, topological constructions, and Antidot geometry arrangements have been investigated for their effectiveness in meeting the criteria for several electronic and computing applications, one of which is the development of a super-fast method for storing data.

The focus of this project was to characterize critical parameters of a superconducting thin film to be used for Antidot patterning. Novel samples of YBCO with a CeOz buffer layer were previously grown on an r-cut sapphire substrate. For characterization, a liquid helium cryostat and an inductive coil system with a built-in heater were used. Automatic testing algorithms were written with LabVIEW to administer the experiment, and results were tabulated and analyzed using Origin. Critical temperature and voltage values of the sample were successfully determined.

Nanoscale Resistive Switching in Oxides

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Resistive switching, a phenomena in which certain materials can be switched between high and low resistance states, shows promise for ResistiveRAM devices that could someday replace flash memory. $SrTiO_3$ (STO) is often used as a model material for resistive switching; however, the underlying physicochemical processes lack a clear understanding, particularly those for electroforming [1]. Electroforming is the one-time application of voltage over time, thereby changing the device from its virgin state and enabling resistive switching. To test switching behavior, epitaxial Fe:STO thin films were deposited on a single crystalline Nb:STO substrate with pulsed laser deposition. For the top electrodes, platinum was deposited via sputtering, patterned with photolithography, and reactive ion etched. Pads were electroformed; formation time was measured and fit to statistical models.

Adjusting to a new culture has been simultaneously wonderful and bewildering. At times, I longed for nothing more than a giant burrito or to have the "y" and "z" keys switched back to their proper locations on my keyboard, yet I cannot deny the joy of eating half of a fried chicken in a Munich biergarten or the awe of visiting Aachen's 1200-year-old Kaiserdom. Living in Germany and traversing Europe was a truly delightful experience.

References: [1] R. Waser, et al., Adv. Mater. 2009, 21, 2632-2663.

Deposition and Characterization of Ruthenium Films for Neural Electrodes

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Neural probes are used to stimulate neurons or record electrical signals, which can be instrumental in understanding the neural network and treating disease. Probes are implanted in the brain and are usually fabricated using biocompatible and bioactive materials. Currently, some probes are microelectrodes; their small size increases selectivity and decreases tissue damage. It is important that materials used have high charge storage capacity and low impedance. We investigated the deposition of ruthenium oxide films on gold, titanium nitride, platinum, and atomic layer deposited ruthenium. The samples were characterized using cyclic voltammetry and impedance spectroscopy to predict their performance for neural probe applications.

The project is based at imec in Leuven, Belgium. Imec focuses on industry-relevant technology solutions ranging from smart electronics to sustainable energy to healthcare. Although we worked hard at imec, during weekends we have found time to visit many other places in Europe such as Amsterdam, Paris, Brussels, and London!

Dry Electrodes for Electroencephalography (EEG) Headsets

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Electroencephalography, or EEG, is the field of measuring and recording the brain's electrical activity. Although it is already widely used to study the brain and its disorders, the EEG can still be improved. Currently, the conventional EEG is read using wet electrodes placed on the scalp. These electrodes, though effective, bring about significant discomfort to the patient for two reasons. First, the skin where the electrode is applied must be rubbed abrasively, and second, an electrolytic gel must be applied to the area of contact. While also being messy, the electrolytic gel dries out within a few hours, restricting any long-term measurement from being taken. For uses such as in newly developed wireless EEG headsets, being able to measure for long periods of time are very important. For that reason, the current study presents the design of a different type of electrode, a "dry" electrode, in which no skin preparation nor gel is necessary. Once fabricated, the dry electrodes are tested in commercial neuroheadsets and then compared to the standard wet electrodes. The results show that dry electrodes have high potential to replace wet ones in EEG headsets.

Chromatin Remodeling by Brahma on DNA and Mono-Nucleosomes

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In nucleated cells, the majority of deoxyribonucleic acid (DNA) is highly compressed into chromatin, a carefully regulated complex of DNA and protein. Nucleosomes, 146 bp dsDNA wrapped around 8-subunit histone complexes, form the basic units of organization in chromatin, and in living cells a suite of remodeling proteins constantly reorganizes nucleosomes to allow or restrict access to genetic information. One such remodeling protein, Brahma (BRM), forms the core motor unit in many larger remodeling complexes in *Drosophila*, but little is understood of the capacity and mechanism by which BRM interacts with DNA or nucleosomes. Through gel assays and observation under AFM, we have investigated BRM functionality as an ATPase and the effects of BRM binding to mono-nucleosomes and bare DNA. As a part of the NNIN iREU Program, this research was conducted in the Bionanoscience (BN) Department at TU Delft in the Netherlands.

The focus of the summer was not only to learn about chromatin remodeling but also about research as a cooperative international effort, an ethic strongly embraced by the BN group. The experience spanned six countries and immersion into the culture of a gorgeous host nation that encouraged evening bicycle tours and a strong sense of camaraderie both in and out of the workplace.

Novel Process to Fabricate Raised Polymer Electrodes for Electroencephalography

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Twenty percent of epileptic patients are unable to receive drugs and must undergo surgery, requiring an invasive procedure to determine the epileptogenic zone. Electrodes are implanted into the brain and neural activity is monitored for one week while electroencephalography (EEG) is used concurrently to create multi-layered recordings. EEG systems use conducting gels to adhere electrodes to the scalp. However, current EEG systems suffer from poor long-term skin adherence and are difficult to apply around the implanted electrodes. The purpose of this work was to develop a novel process for the fabrication of flexible conducting polymer electrodes for EEG which would record long-term signals. As the electrode insulator, Parylene C (PaC) was deposited into a flexible, biocompatible, thin film. The electrodes were patterned via photolithography and consisted of metal deposited on a conducting polymer layer. To provide high conductivity and biocompatibility, poly(3,4-thylenedioxythiophene) doped with poly(styrene sulfonate) (PEDOT:PSS) was used as the conducting polymer. The electrodes were designed to protrude from the PaC matrix through the use of a sacrificial polyvinyl alcohol (PVA) layer. The sacrificial layer increased the surface contact area at the skin to electrode interface while decreasing impedance. Once fabrication was completed, the device was released from the glass substrate by dissolving the PVA in water, resulting in conformable and flexible electrodes.

Fabrication of Organic Transistors Using Inkjet Printing

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Inkjet printing shows potential to manufacture low-cost electronics, specifically biosensors. Inkjet printing is a non contact, direct write process that has no need for masks, excessive chemical treatments, or cumbersome fabrication steps. In this project, a Dimatix Materials Printer was used to optimize printing parameters of three types of inks and print organic electrochemical transistors on a biocompatible substrate, for use as biosensors. The printing parameters were optimized for a silver nanoparticle ink, a polyimide (PI) ink, and a poly(3,4-ethylene dioxythiophene)-poly(4-styrenesulfonate) (PEDOT:PSS) ink. Using these inks and the optimized printing parameters, two types of organic electrochemical transistors (OECTs) were fabricated and tested. The first OECT was a multilayered device that utilized all three inks. The second device was a planar, all-PEDOT:PSS OECT. The biosensor capabilities of the OECTs were tested using phosphate buffered saline (PBS) as the electrolyte. The results indicate that both device designs were successfully fabricated. The all-PEDOT:PSS OECTs were found to be the most robust and sensitive to electrical characterization.

Systematic Investigation of Morphology of Polymer:Bis-Fullerene Blends for Bulk Heterojunction Organic Photovoltaic Cells

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Active layer morphology plays an essential role in determining the performance of polymer:fullerene bulk heterojunction (BHJ) organic photovoltaic (OPV) cells. Upon processing with several amorphous polymers, a promising new bis-fullerene derivative (bis-A, for confidentiality) was recently found to exhibit undesired formation of holes with diameter on the order of 10's of nm at a density of approximately 25 μm^{-2} (~ 0.1-1.0% of film surface area). This poor film formation significantly hinders device performance. We have prepared and characterized BHJ thin films to systematically study the processing conditions under which these holes arise. Blends of poly(3-hexylthiophene) (P3HT):bis-A and P3HT:bis-PCBM were investigated by comparison to the well-known P3HT:PCBM (phenyl-C_{61}-butyric acid methyl ester) system. The blends were characterized by atomic force microscopy, ultraviolet-visible spectrophotometry, and contact angle measurements. Throughout the annealing temperature range of 27°C-130°C, P3HT:Bis-A(1:4) always exhibits hole formation. Furthermore, at room temperature, films of P3HT:bis-PCBM(1:4) also exhibit holes, indicating hole formation may be a general property of bis-fullerene derivatives at high loadings within polymer films. Absorption measurements suggest that the holes form a porous network in the bulk, as we observe an inverse relationship between attenuation coefficient and bis-A loading, contrary to the direct dependence of attenuation coefficient on the loading ratio of the reference P3HT:PCBM. Penetration of solvent through the 1:4 and 1:3 P3HT:bis-A films during contact angle measurements further indicates that the holes form a porous network in the bulk.

Characterization of Optoelectronic Properties of Colloidal Quantum Dots in a Nanogap

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This work focuses on a fundamental exploration of charge transport through a self-aligned nanogap which has been deposited with colloidal cadmium selenide (CdSe) quantum dots via solution phase processing. Characterization of charge transport through the gap, which is only a few nanometers wide, centers around measurements made at room and cryogenic temperatures and the response of the device as a result of interaction with light.

CAMPUS MAP

ACADEMIC/RESEARCH

	ID#	GRID
Advanced Wood Products Laboratory (AWLP)	158	C7
Aerospace Combustion Laboratory, Ben T. Zinn (635 Strong St.)	151	C8
Architecture Annex	60A	E5
Architecture Building (East)	76	E5
Architecture Building (West)	75	E5
Baker Building (GTRI)	99	D3
Boggs Building	103	D5
Broadband Institute Residential Laboratory, Aware Home (479 Tenth St.)	152	C3
Bunger-Henry Building	86	D5
Callaway Manufacturing Research Center	126	C5
Centennial Research Building	790	D3
Center for Assistive Technology and Environmental Access (CATEA)	128	C3
Centergy One	176	G5
Cherry Emerson Building	66	E4
Computing, College of	50	E5
Coon Building (Psychology)	45	E7
Couch Building (Music)	115	B4
Crosland Tower (Library)	100	E6
Daniel Laboratory	22	F6
Economic Development Building	173	G5
Engineering Science & Mechanics Building	41	E7
Food Processing Technology Building	159	C8
Ford Motor Company Environmental Science and Technology Building (Ford ES&T)	147	E4
Global Learning and Conference Center	170	G5
GTRI Conference Center	141	E1
GTRI Research (430 Tenth St.) North	61	C3
GTRI Research (430 Tenth St.) South	61A	C3
Guggenheim Aeronautics Building	40	E7
Heffernan House (Architecture)	720	F5
Hinman Building	51	E6
Howey Physics Building	81	D5
Industrial and Systems Engineering (Groseclose Building & ISyE Annex)	58	C5
Institute of Paper Science and Technology	129	B3
Instructional Center	55	C5
ISyE Annex	57	C6
Ivan Allen College of Liberal Arts (781 Marietta St.)	137	B6
Klaus Advanced Computing Building	153	E5
Knight Building (Aerospace Engineering)	101	E7
Library and Information Center	77	E6
Love Manufacturing Building (MRDC II)	144	C5
Management, College of	172	G5
Manufacturing Related Disciplines Complex (MRDC)	135	D5
Marcus Nanotechnology Building	181	D4
Mason Building (Civil & Environmental Engineering)	111	D5
Mechanical Engineering Research Building	46	E7
Molecular Science & Engineering Building	167	E4
Neely Research Center	87	D4
O'Keefe - Main Building	33	F4
OMED (Minority Educational Development)	25	E6
Petit Biotechnology Building	146	E4
Pettit Building (Microelectronics Research Center)	95	E5
Price Gilbert Library and Information Center	77	E6
Rich Computer Center	51D	E6
Savant Building	38	E7
Skiles Classroom Building	2	E6
Smith Building	24	E6
Structural Engineering and Materials Research Lab (625 Lambert St.)	149	B7
Sustainable Education (Allen Building)	145	D5
Swann Building	39	E7
Tech Way Building	136	C7
Technology Square Research Building (TSRB)	175	G5
Van Leer Building (Electrical and Computer Engineering)	85	E5
Weber Building I	84	E7
Weber Building II	98	E7
Whitaker Building	165	E4

RESIDENCE HALLS

	ID#	GRID
Armstrong Residence Hall	105	C4
Brown Residence Hall	7	F7
Caldwell Residence Hall	109	B4
Center Street Apartments	132	C4
Cloudman Residence Hall	13	F7
Crecine Apartments (formerly Hemphill)	131	C3
Eighth Street Apartments	130	B3
Family Housing (Tenth & Home)	180	E3
Field Residence Hall	90	F6
Fitten Residence Hall	119	C4
Folk Residence Hall	110	B4
Freeman Residence Hall	117	C5
Fulmer Residence Hall	106	C4
Glenn Residence Hall	16	F6
Graduate Living Center	52	E3
Hanson Residence Hall	93	G6
Harris Residence Hall	11	F7
Harrison Residence Hall	14	G7
Hefner Residence Hall	107	C4
Hopkins Residence Hall	94	F6
Howell Residence Hall	10	G7
Matheson Residence Hall	91	F6
Maulding Residence Hall	65A	B5
Montag Residence Hall	118	C4
Nelson Residence Hall	64B	B4
North Avenue Apartments	191	F8
Perry Residence Hall	92	G6
Sixth Street Apartments	65	B5
Smith Residence Hall	6	G7
Stein, Hayes, Goldin, and Fourth St. E Houses	134	F8
Towers Residence Hall	15	G8
Undergraduate Living Center	64A	B4
Woodruff Residence Hall	116	B4

STUDENT ORGANIZATIONS

	ID#	GRID
Alpha Chi Omega	331	F6
Alpha Delta Pi	334	F6
Alpha Epsilon Pi	300	F6
Alpha Gamma Delta	333	F5
Alpha Phi Omega	120	D4
Alpha Tau Omega	302	F5
Alpha Xi Delta (Mewborn and Dull House)	322	F4
Beta Theta Pi	303	F5
Chi Psi	305	F6
Delta Chi	335	F5
Delta Sigma Phi	307	F5
Delta Sigma Theta	337	F6
Delta Tau Delta	308	E5
Delta Upsilon	309	F5
Kappa Alpha	310	F5
Kappa Sigma	311	F4
Lambda Chi Alpha	312	F5
Phi Delta Theta	314	F6
Phi Gamma Delta	315	F5
Phi Kappa Psi	304	F6
Phi Kappa Sigma	316	F5
Phi Kappa Tau	317	F5
Phi Kappa Theta	318	F5
Phi Mu	362	E5
Phi Sigma Kappa	319	F5
Pi Kappa Alpha	320	E5
Pi Kappa Phi	336	F5
Psi Upsilon	321	F5
Sigma Alpha Epsilon	323	F5
Sigma Chi	324	F5
Sigma Nu	325	F6
Sigma Phi Epsilon	326	F5
Tau Kappa Epsilon	327	F5
Theta Chi	328	F5
Theta Xi	329	F5
Zeta Beta Tau	330	F4
Zeta Tau Alpha	338	F5

ATHLETICS

	ID#	GRID
Alexander Memorial Coliseum and Annex	73	F3
Bobby Dodd Stadium	17	F7
Campus Recreation Center (CRC)	160	C5
Challenge Course	367	C4
Chandler Stadium	168	E4
Edge Intercollegiate Athletic Center	18	F6
Grant Field	355	F7
Griffin Track	342	E4
Luck Building	73A	F3
Mewborn Field	196	F4
Moore Tennis Center	80	F3
O'Keefe Gym	33A	F4
Rice Center for Sports Performance	18A	F6
Rose Bowl Field	347	F4
Stamps Field	348	C5
Women's Softball Stadium	196	F4

RELIGIOUS ORGANIZATIONS

	ID#	GRID
Baptist Student Union	339	F6
Catholic Center	341	F5
Christian Campus Fellowship	332	F5
Lutheran Campus Ministry	343	F5
Methodist Center (Wesley Foundation)	344	F5
Presbyterian Student Center	346	F6

ADMINISTRATION/SERVICES

	ID#	GRID
Army ROTC	73A	F6
Academy of Medicine	156	H4
Admissions (Moore Success Center)	31	F7
Alumni/Faculty House	3	F7
Barnes & Noble @ Georgia Tech (Bookstore)	172	G5
Brittain Dining Hall	12	F7
Bursar's Office (Lyman Hall)	29A	F7
Business Services Building	164	C7
Carnegie Building	36	F7
Central Receiving	164	C7
Child Care (Landon Learning Center)	791	D2
Commander Building (Reserve)	105	C4
Dean of Students (Smithgall)	123	D6
Emerson	29B	F6
Evans Administration Building	35	E7
Facilities Building	32	F4
FASET Orientation Office (ISyE Annex)	57	C6
Ferst Center for the Arts (349 Ferst Dr.)	124	D6
French Building	30	E7
Financial Aid (Moore Success Center)	31	F7
Georgia Tech Hotel & Conference Center	171	G5
Griswell Building	162	B7
Holland Building (Wheels)	26	E6
Hopkins Building	184	B6
Housing Office	123	D6
Human Resources	142	C6
Junior's Grill	74	F7
Landon Learning Center (Child Care)	791	D2
Language Institute (O'Keefe)	33	F4
Lyman Hall (Bursar's Office)	29A	F7
Moore Student Success Center	31	F7
Navy ROTC	59	F6
O'Keefe Custodial Services Building	33B	F4
OIT Planning and Programming	156	B5
President's Office (Carnegie)	36	F7
Parking Office	170	H5
Police (Georgia Tech Police Department)	46	C4
Post Office / Student Center	104A	D6
Printing and Copying Services (811 Marietta St.)	138	B6
Registrar (Tech Tower)	35	E7
Research Administration Building	155	C3
Research Administration Addition	155B	C3
Southern Regional Education Board	125	B3
Student Center Commons (Penny and Roe Stamps)	114	D6
Student Services Building (Smithgall)	123	D6
Student Success Center (Admissions)	31	F7
Tech Tower (Evans)	35	E7
Wardlaw Center	47	F7
Warehouse (650 Ethel St.)	169	A2
Wenn Student Center / Post Office	104	D6
Whitehead Building (Health Services)	177	C6

GREEN SPACE

	ID#	GRID
Acuity Brands Plaza	366	H5
Alumni Park	349	B5
Amphitheater	351	D6
Callaway Plaza	353	F6
Couch Park (Burger Bowl Field)	340	C4
Harrison Square	352	E7
Kessler Campanile	350	D6
Mayer Memorial Garden	354	E6
Suddath Courtyard	370	E4
Tech Green	358	E6
Tech Tower Lawn	363	F7
Third Street Tunnel	360	G8

PARKING DECKS

	ID#	GRID
Burge Parking Deck	8	F7
Campus Recreation Center Parking Deck	162	C5
Curran Street Parking Deck	139	B4
Family Housing Parking Deck	182	E3
GTRI Parking Deck	141B	E1
North Avenue Apartments South Parking Deck	190	F8
North Campus Parking Deck	148	D3
Peters Parking Deck	6	F6
Student Center Parking Deck	54	D6
Technology Square Parking Deck	174	G5
Visitor Parking	42	D6