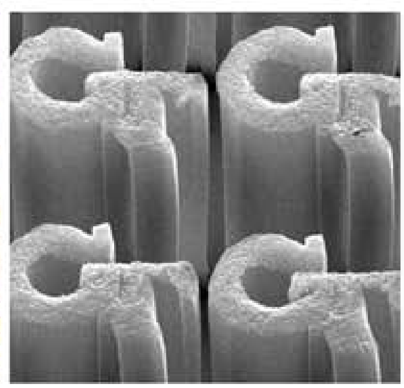
The 2013 NNIN Convocation

NNIN
Nanoscale Science, Engineering & Technology

August 11-14, 2013

Georgia Institute of Technology





Georgia Tech Nanotechnology Research Center blank page

2013 NNIN REU Convocation

Georgia Institute of Technology, Atlanta, GA

Sunday • August 11, 2013 • Marcus Nanotechnology Building

12:00-5:00 p.m. Intern Check-In at Regency Suites Hotel

6:00-7:00 p.m. "TechCaching" (One Smart Phone per Team is Needed)

7:00-8:30 p.m. Welcome and Pizza Party

Monday • August 12, 2013 • Clough Commons Building

6:30-8:00 a.m. Breakfast for Interns at Hotel *(none at convocation)*

8:30- 8:45 a.m. **Welcome by Dr. Oliver Brand**,
Interim Director of the Institute of Electronics and Nanotechnology

Announcements

Session C1 Clough Commons Room 152 (6 talks)

Moderator: Michael Deal

Session C2 Clough Commons Room 102 (6 talks)

Moderator: Nancy Healy

9:25 a.m.	Mr. Tyler Erjavec (Cornell) *Area-Selective Atomic Layer Deposition (ALD): New Recipe Development*	page 22
9:35 a.m.	Mr. Michael West (WUSTL) *Solid-State Pulse NMR of (CdSe)13(propylamine)13*	page 54

9:45-10:05 a.m. Break

Session C3 Clough Commons Room 152 (5 talks)

Moderator: Trevor Thornton

10:05 a.m.	Mr. Christopher Addiego (UW) *Fabrication of Graphene Field Effect Transistors on Boron Nitride Substrates*	page 10
10:15 a.m.	Ms. Brandi Burton (ASU) *Low-Temperature Cu Segregation and Oxidation in Microwaved Ag-Cu Alloys*	page 16
10:25 a.m.	Ms. Deanna Lanigan (WUSTL) *Improving Lithium Ion Battery Performance with Dopant Substitution*	page 32
10:35 a.m.	Ms. Jaelin Quinn (Georgia Tech) *Influence of Al_2O_3 Coating on the Annealing Behavior of Si Nanowires*	page 45
10:45 a.m.	Mr. Jeremy Leshin (WUSTL) *Preparation of Transparent Conducting $CuAIO_2$ Foils*	page 33

Session C4 Clough Commons Room 102 (5 talks)

Moderator: Kathy Gehoski

10:05 a.m.	Mr. Suman Gunasekaran (Minnesota) *Fabrication of Nanofluidic Devices for DNA Confinement*	page 25
10:15 a.m.	Mr. Corey Landry (Harvard) *Design of Synthetic Protein Membranes Using Droplet Microfluidics*	page 32
10:25 a.m.	Ms. Ayobami Adeleke (Howard) *Binding of DU145 Prostate Tumor Cells on SiC*	page 10
10:35 a.m.	Mr. Dakota Crisp (UT Austin) *System Automation for High Throughput Biosensor*	page 20
10:45 a.m.	Ms. Sarah Nainar (Stanford) *Identifying the Biomechanical Effects of UV Resistant Molecules and Nanoparticles on Human Skin*	page 40

10:55-11:15 a.m. Break

Session C5 Clough Commons Room 152 (4 talks)

Moderator: Christine Wood

11:15 a.m.	Mr. Dylan Barber (Stanford) *Use of Field-Induced Surface-Organometallic Interactions to Control Selectivity in Rhodium-Catalyzed Organic Reactions*	page 12
11:25 a.m.	Ms. Kris Beykirch (Cornell) *Effect of Reactive Ion Etching on Laser-Annealed Low-k SiCOH Materials*	page 13
11:35 a.m.	Mr. Satoshi Anada (PSU) *Si/TiO_2 Core/Shell Nanowire for Gas Sensor Arrays on Si CMOS*	page 11
11:45 a.m.	Mr. Kosuke Wataya (Michigan) *Radio Frequency Switches Using Phase Change Material*	page 53

Session C6 Clough Commons Room 102 (4 talks)

Moderator: Joyce Allen

11:15 a.m. **Ms. Crystal Chukwurah (Howard)** .... **page 18**
Growth of Graphene on Various Substrates

11:25 a.m. **Ms. Christine Le (WUSTL)** .... **page 33**
Crumpled Graphene Oxide Nanostructures for Advanced Water Treatment Technologies

11:35 a.m. **Ms. Michelle Chen (UCSB)** .... **page 17**
Development of Platinum@Reduced Graphene Oxide Catalyst for Fuel Cell Applications

11:45 a.m. **Ms. Anne Showalter (ASU)** .... **page 48**
Micro-Scale Microbial Fuel Cell: Petroleum Biosensing

11:55-1:00 p.m. Lunch at Stamps Student Center (voucher needed)

Coordinators Meeting Second Floor Atrium

Session C7 Clough Commons Room 152 (6 talks)

Moderator: Mack Carter

1:00 p.m. **Ms. Meghan Kazanski (Michigan)** .... **page 29**
Development of Microfluidic Devices for use in Immunophenotyping

1:10 p.m. **Mr. Ang Li (Harvard)** .... **page 34**
Curved Functionalized Microfluidic Channels for Study of Cell Dynamics

1:20 p.m. **Ms. Seung Yeon Kim (Minnesota)** .... **page 30**
Fabrication of "Barcode" Nanowires for Multiplexed Detection in Biological Assays

1:30 p.m. **Mr. Ted Kocher (Minnesota)** .... **page 30**
Effects of Cellular Architecture on MDA-MB 231 Breast Cancer Cell Motility

1:40 p.m **Mr. Zachary Pritchard (UCSB)** .... **page 44**
Fabrication of Nano Ion Pumps for Retinal and Neural Prosthesis

1:50 p.m. **Mr. Gabriel Lopez Marcial (Cornell)** .... **page 35**
Designing a Microfluidic Device to Measure the Deformability of Cancer Cells

Session C8 Clough Commons Room 102 (6 talks)

Moderator: Brandon Lucas

1:00 p.m. **Mr. Kiwamu Nishimoto (UCSB)** .... **page 41**
WSi_2 Films for Superconducting Resonators

1:10 p.m. **Mr. Andinet Desalegn (Michigan)** .... **page 21**
Nanoscale High-Speed Transparent Electronics Using
E-Beam Patterning of Zinc Tin Oxide Thin Film Transistors

1:20 p.m. **Mr. Kenton McFaul (PSU)** .... **page 37**
Fabricating Nanostructures to Modulate Local Potential in Graphene

1:30 p.m. **Ms. Veronica Medrano (Howard)** .... **page 38**
Growth and Characterization of Synthetic Diamond

1:40 p.m **Mr. Tomoyuki Inoue (ASU)** .... **page 28**
Fabrication of All-Aluminum n-Type Silicon Solar Cells

1:50 p.m. **Mr. Alexandro Rocha (UT Austin)** .... **page 47**
Designing Directional Micro-Machined Microphones

2:00-2:15 p.m. Break

Session C9 Clough Commons Room 152 (6 talks)

Moderator: Kathryn Hollar

2:15 p.m. Ms. Shelby Pursley (Georgia Tech) .... page 45
Electrospun Nanofibers for Regenerative Medicine

2:25 p.m. Mr. John Schwalbe (UW) .... page 48
Studying the Interfacial Dynamics of Miscible Fluids with Microfluidics

2:35 p.m. Mr. Justin Nauman (WUSTL) .... page 40
Effects of Hydrophilic Membrane Modifications and Natural Organic Matter Fouling on Reverse Osmosis Membrane Performance

2:45 p.m. Ms. Jacqueline Ong (Stanford) .... page 42
Stabilizing Fiber Optic Pressure Sensor Measurements by Fabricating an Enclosed Photonic Crystal Cavity

2:55 p.m. Mr. Brandon Pereyra (Cornell) .... page 43
Surface Scatterers on Slab-Wave Guides for Uniform Bacteria Growth

3:05 p.m. Mr. Peter Su (Georgia Tech).... page 49
Dynamics of Bacterial Quorum Sensing in Microfluidic Devices

Session C10 Clough Commons Room 102 (6 talks)

Moderator: Samantha Cruz

2:15 p.m. Mr. Eric Reichwein (UCSB).... page 46
Electron Blocking Layer in Gallium Nitride Devices

2:25 p.m. Mr. Bradlee Beauchamp (Colorado) .... page 12
Fabricating Dual-Sided Micro Lenses and High Frequency Talbot Diffraction Gratings Using Binary Masks

2:35 p.m. Ms. Priyanka Gaur (UT Austin) .... page 24
Voltage-tunable Plasmonic Metamaterials Based on Stark Tunable Intersubband Polaritons

2:45 p.m. Mr. Christopher Green (ASU) .... page 25
Silicon Nanowires for Optical Light Trapping in Solar Cells

2:55 p.m. Mr. Joshua Michalenko (PSU) .... page 39
High Strain Low Voltage Induced Densified Vertically Aligned Carbon Nanotube Ionic Actuators

3:05 p.m. Mr. Arthur Bowman, III (Michigan) .... page 15
Infrared Filtering via Sub-Wavelength Gratings for Hyperspectral Imaging

3:15-3:40 p.m. Presentation on Fellowships, Clough Commons Room 150

Presenter: Dr. Lynn Rathbun

3:40-3:55 p.m. Break

Session C11 Clough Commons Room 152 (5 talks)

Moderator: Melanie-Claire Mallison

3:55 p.m. Mr. John Binion (UT Austin) .... page 14
Inkjet Printed Interconnects for Multilayer Flexible Electronics

4:05 p.m. Mr. Daichi Oka (UT Austin).... page 41
Carbon Coated Tin-Seeded Silicon Nanowires for Lithium-Ion Battery Anodes

4:15 p.m. Mr. Christopher Florencio-Aleman (Georgia Tech) .... page 23
Nanocharacterization of Wood Fibers in Cement

4:25 p.m. Mr. Harrison Goldwyn (UW) .. .. page 24
Understanding Magnetic Plasmon Mode Mixing using Electron Energy Loss Spectroscopy

4:35 p.m. Mr. Rafael Haro (Cornell).. .. .. page 26
Determination of Strength Degradation Mechanisms
of Native Oxide on Silicon Nanostructures

Session C12 Clough Commons Room 102 (5 talks)

Moderator: Jim Marti

3:55 p.m. Ms. Hannah Bailey (WUSTL).. .. .. page 11
Crumpled Graphene for Applications in Energy and the Environment

4:05 p.m. Mr. Caleb Christianson (Cornell).. .. .. page 18
An Experimental and Theoretical Investigation
of Ultrasound Transmission in Bubbly PDMS Phononic Crystals

4:15 p.m. Mr. Yuki Sunayamas (Colorado) .. .. page 50
Graphene-Based Electro-Optic Modulators

4:25 p.m. Ms. Katelyn Conrad (Colorado). .. .. page 19
Ion Transport Through Porous Graphene

4:35 p.m. Mr. Michael Sunyak (Colorado). .. .. page 50
Graphene-Based Electro-Optic Modulator Fabrication

4:45 Adjourn

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

Viva Las Vegas

Tuesday • August 13, 2013 • Clough Commons Building

6:30-8:00 a.m. Breakfast for Interns at Hotel

8:30 - 8:35 a.m. Announcements

Session C13 Clough Commons Room 152 (6 talks)

Moderator: Nathan Reed

8:35 a.m. Ms. Allison Wustrow (PSU) .. .. page 55
Directed Self Assembly of Mixed Nanowire Populations via Lithographic Microwells

8:45 a.m. Mr. Kevin Tkacz (UCSB). .. .. page 51
Nanostructuring Diamond for Quantum Sensing

8:55 a.m. Mr. John Ferrier, Jr. (Harvard).. .. .. page 23
Engineering Three-Dimensional Biological Scaffolds
Using a Modified Rotary Jet Spinning System

9:05 a.m Ms. Azusa Miyagawa (Michigan) .. .. page 39
Direct Nano Patterning of Anisotropic Conjugated Polymer

9:15 a.m. Mr. Connor McMahan (Colorado) .. .. page 37
Electro-Mechanical Characterization of Stretchable and Flexible Nanowires

9:25 a.m. Mr. Yuki Hamasaki (UW) .... page 26
Poly(3-alkyldithienothiophene): Synthesis, Structure and Optical Properties

Session C14 Clough Commons Room 102 (6 talks)

Moderator: Lynn Rathbun

8:35 a.m. Mr. Tyler Burkett (Georgia Tech) .... page 16
Silver Nanoplates: Structural Stability and Optical Properties

8:45 a.m. Mr. Benjamin Helfrecht (ASU) .... page 27
Zinc Oxide Based Solar Cells for Self-Powered Smart Window Application

8:55 a.m. Ms. Alice Perrin (Cornell) .... page 44
Spin Manipulation of Antiferromagnetic Devices

9:05 a.m Mr. Andrew Stephan (Minnesota) .... page 49
Infrared Photodetectors With 2D Materials

9:15 a.m. Ms. Katherine Warthen (Michigan) .... page 52
The Impact of MEMS-Produced Micro-Electrode Material Coating on Dental Plaque Biofilm Growth

9:25 a.m. Ms. Christine Truong (PSU) .... page 51
The Study of Disposable Substrates in Surface Acoustic Wave (SAW) Devices

9:35-9:55 a.m. Break

9:55-10:55 a.m. Panel Session

Presenters: Dr. Samantha Andrews, Georgia Institute of Technology, Dr. Mikkel Thomas, Georgia Institute of Technology, Dr. Ranjani Balasubramaniam-Siemens Industry, Inc., Ms. Janet Cobb-Sullivan-Lumense, Inc. and Dr. David Safranski, MedShape, Inc.

10:55-11:10 a.m. Break

Session C15 Clough Commons Room 152 (4 talks)

Moderator: Samantha Andrews

11:10 a.m. Ms. Connie Wu (Cornell) .... page 54
Full Body Silicon Medical Tweezers for Cancerous Tissue Detection and Characterization

11:20 a.m. Ms. Ashlyn Young (Minnesota) .... page 57
Exploring the Effects of Theophylline on Neutrophil Function in Inflammatory Diseases

11:30 a.m. Ms. Hannah Zeitler (UW) .... page 58
Azobenzene Modified DNA for Light-Induced DNA Stringency

11:40 a.m. Ms. Jeanne Xu (WUSTL) .... page 56
Synthesis of Metal Supported Catalysts for the Hydrogenolysis of Lignin

11:50-1:15 p.m. Lunch and Photos at Clough Commons (box lunch)

1:15-2:10 p.m. Panel Session on the iREU Program

Presenters: Japan: Colin Burns-Hefner, Melinda Jue, Stephen Olson, Adam Overvig, Radu Reit, Emily Ross, Jacob Rothenberg, Andrew Tam, and Geoffery Vrla. **Germany:** Adam Blonsky and Christopher Nakamoto. **France:** Kaleigh Margita and Brianna Thielen. (Poster Abstracts begin on page 59)

2:10-2:20 p.m. Poster Set Up at Clough Commons

2:20-3:30 p.m. Posters A-L (by Last Name)

3:30-3:40 p.m. **Poster Set Up at Clough Commons**

3:40-4:50 p.m. **Posters M-Z (by Last Name)**

4:50 Adjourn

6:00-10:00 p.m. Evening Event

Game Room and BBQ

At Student Recreation Center

Wednesday • August 14, 2014 • Clough Commons Building

6:30-8:00 a.m. Breakfast for Interns at Hotel

8:30-8:35 a.m. Announcements

Session C16 Clough Commons Room 152

Moderator: James Griffin

8:35 a.m. **Ms. Hannah Oros (UT Austin)** . . . . **page 42**
Gender and Nanoscientists: The Public Communication of Nanotechnology

8:45 a.m. **Mr. Charles Yates (Georgia Tech)** . . . . **page 57**
Big Ideas on Small Matters: A Multi-Method Approach to Understanding Knowledge Transfer Practices in the NNIN

8:55 a.m. **Mr. Fumiya Kurokawa (PSU)** . . . . **page 31**
Thermodynamic Control of Lead Content in the Piezoelectric Thin Film

9:05 a.m. **Ms. Jill Wenderott (UCSB)** . . . . **page 53**
Fabrication and Characterization of InGaAs Metal-Oxide-Semiconductor Capacitors (MOSCaps) with HfO_2 Dielectrics

9:15 a.m. **Mr. Frank Luciano (UCSB)** . . . . **page 35**
Mobility of the Two-Dimensional-Electron-Gas in Lattice-Matched InAlN/GaN Grown by Ammonia Molecular Beam Epitaxy

9:25 a.m. **Mr. Shay Wallace (Harvard)** . . . . **page 52**
Improvement of Tin Sulfide Solar Cell Efficiency

9:35-9:50 a.m. Break

9:50-10:50 a.m. **Panel: Innovation, Entrepreneurship, and Commercialization**

Moderator: Joy Hymel. Panel Participants from Georgia Tech's Enterprise Innovation Institute: Keith McGreggor-Director, VentureLab, Dan Ciprari-Entrepreneur in Residence, Lynne Henkiel, Director, Entrepreneurial Extension CEO of ATDC Company

10:50- 11:10 a.m. Break

Session C17 Clough Commons Room 152

Moderator: Jamey Wetmore

11:10 a.m. Mr. Peter Kim (UW) .... page 29
Cellular Migration on Curved Substrata

11:20 a.m. Ms. Lisa Kriegh (ASU) .... page 31
Microfluidics for the Study of Breast Cancer

11:30 a.m. Mr. Ming-Lun Wu (Minnesota) .... page 55
Micro-Fabrication of Chemical Field-Effect Transistor

11:40 a.m. Ms. Alexandra Benson (UW) .... page 13
Characterization of Polymer Films on Silicon Photonics Devices for Blood Analysis

11:50 a.m. Ms. Dara Bobb-Semple (Stanford) .... page 15
Developing Nanoscale Electrodes for Sensitive Detection of Brain Cell Activities

12:00 p.m. Ms. Stephanie Cone (Stanford) .... page 19
Investigation of Microfluidic Integration
in Magneto-Nanosensor Based Protein Biomarker Detection

12:10-1:10 Lunch at Stamps Student Center (voucher needed)

1:10- 2:40 p.m. Societal and Ethical Issues

Presenters: Jamey Wetmore, Ira Bennett, and Kiera Reifschneider-Wegner,
Center for Nano and Society, Arizona State University

2:40-3:00 p.m. Break

Session C18 Clough Commons Room 152

Moderator: Ira Bennett

3:00 p.m. Mr. Moath Othman (Cornell) .... page 43
Electrokinetic Characterization of Nanoscale Metal Oxide Films

3:10 p.m. Ms. Audre Ramey (Michigan) .... page 46
Electrohydrodynamic Jet Printing on Hydrogel Substrates for Cell Culturing Applications

3:20 p.m. Mr. Joseph Rivas (Michigan) .... page 47
Deposition and Characterization of
Magnetic Permalloy for Future Endomicroscope Actuators

3:30 p.m. Ms. Samantha Corber (WUSTL) .... page 20
Cisplatin-based Metal Organic Framework Nanoparticles
for Target Drug Delivery and Tumor Imaging

3:40 p.m. Mr. Marco De Lira (Howard) .... page 21
Fabrication of Accelerometers using Paper MEMS Substrates

3:50 p.m. Wrap up and adjourn

Evening on Your Own

Thursday • August 15, 2014 • Everyone Departs!

REU & iREG Presentations & iREU Poster Abstracts

In Alphabetical Order

Fabrication of Graphene Field Effect Transistors on Boron Nitride Substrates

Christopher Addiego
Physics, Carnegie Mellon University

NNIN REU Site: NanoTech User Facility, University of Washington, Seattle, WA
NNIN REU Principal Investigator: Xiaodong Xu, Physics, University of Washington
NNIN REU Mentor: Grant Aivazian, Physics, University of Washington
Contact: chris.addiego@comcast.net, xuxd@uw.edu, aivazian@uw.edu

Graphene is a two dimensional crystal of carbon atoms that has applications to new electronics and optoelectronics when fabricated as a field effect transistor (FET). The quality of these FETs is quantified partly by the carrier mobility of the device. Despite graphene's high intrinsic carrier mobility, the carrier mobility of the devices used in the lab is limited by the surface roughness of the SiO_2 substrate and residues deposited during the fabrication process. The goal of this project is to determine a procedure for fabricating graphene FETs on boron nitride (BN) substrates to create devices with improved carrier mobility. A combination of chemical solvents and annealing procedures were used to clean the devices during fabrication. We used an atomic force microscope to identify the residues deposited on the BN and the graphene and a sensitive preamplifier to measure the carrier mobility of the devices. After varying several parameters in the fabrication procedure, we found that washing the BN substrate in acetone and isopropanol prior to transferring the graphene provides the devices with the highest carrier mobility (~350 cm^2/Vs). However, this value is much less than that of typical graphene FETs on SiO_2 substrates, indicating the procedure can still be improved.

Binding of DU145 Prostate Tumor Cells on SiC

Ayobami Adeleke
Chemistry, Delaware State University

NNIN REU Site: Howard Nanoscale Science and Engineering Facility, Howard University, Washington, DC
NNIN REU Principal Investigator: Dr. Tina Brower-Thomas, Chemical Engineering, Howard University Nanoscale Facility (HNF) and Dr. Gary Harris, Electrical Engineering, Howard University
NNIN REU Mentor: Dr. Paulette Furbert-Harris, Cell Biology, Howard University Cancer Center
Contact: Aaadeleke11@students.desu.edu, tina.browerthomas@howard.edu

The efforts of this investigation are towards the development of a device that can differentiate cells by their electrical properties. Three forms of silicon carbide (SiC) were used as substrates and include 6HSiC, highly doped 6HSiC and 3CSiC grown on Si. Prostate tumor cells from the DU145 cell line were cultured and counted. The cells were then bound to the given substrates at various concentrations. The DU145 cell line was observed by optical microscopy. It was determined that 5×10^4 was the most effective concentration for binding a monolayer of cells on both 6H-SiC and highly doped 6H-SiC. The highly doped (HD) 6H SiC substrate was the most effective substrate for the binding of the cells. Measuring the cells with a caliper we were able to determine the length and width of the cell. Atomic force microscopy (AFM) was employed and additional details about the cell morphology were observed to include three dimensional images. The electrical properties of the DU145 prostate tumor cell line were investigated.

Si/TiO_2 Core/Shell Nanowire for Gas Sensor Arrays on Si CMOS

Satoshi Anada
Materials and Manufacturing Science, Osaka University

NNIN iREG Site: Penn State Nanofabrication Laboratory, The Pennsylvania State University, University Park, PA
NNIN iREG Principal Investigator: Theresa S. Mayer, Electrical Engineering, The Pennsylvania State University
NNIN iREG Mentor: Xiahua Zhong, Electrical Engineering, The Pennsylvania State University
Contact: Anada@uhvem.osaka-u.ac.jp, tsm2@psu.ed, xxz138@psu.edu

Recently, there has been growing interesting in adding non-traditional functions to Si CMOS by integrating new nanomaterials and devices directly onto CMOS circuits. Molecular and metal oxide nanomaterials designed to produce a large electronic signal in response to chemical vapors or biological molecules offer sensing capabilities. This research focused on the synthesis and microstructural analysis of TiO_2-based core/shell nanowires for gas sensor arrays, and the use of electric-field assisted deterministic assembly for positioning arrays of individual nanowires at predefined locations on a Si substrate. The goal of this project is to clarify the relationship between the microstructure of the metal-oxide nanowires and their sensitivity to different air pollutants in the environment. The nanowires were prepared by atomic layer deposition of a TiO_2 on high-aspect-ratio Si nanowires obtained by reactive ion etching of a high resistivity Si substrate patterned using colloidal lithography. The TiO_2 microstructure was determined by transmission electron microscopy. In the as-deposited sample, the shell of the nanowire was found to be amorphous TiO_2. After annealing at 873K for two hours, the amorphous phase transformed into a crystalline phase, identified as anatase TiO_2. These nanowires are currently being integrated onto lithographically patterned Si substrates using electric-field assisted deterministic assembly for subsequent device integration and sensor testing.

Crumpled Graphene for Applications in Energy and the Environment

Hannah Bailey
Engineering Physics, Rose-Hulman Institute of Technology

NNIN REU Site: Nano Research Facility, Washington University in St. Louis, St. Louis, MO
NNIN REU Principal Investigator: Pratim Biswas, Energy, Environmental and Chemical Engineering, Washington University in St. Louis
NNIN REU Mentor: Wei-Ning Wang, Energy, Environmental and Chemical Engineering, Washington University in St. Louis
Contact: baileyh@rose-hulman.edu, pbiswas@wustl.edu, wangwn@seas.wustl.edu

Carbon Capture and Sequestration (CCS) is presently used to reduce carbon emissions through the amine absorption and underground storage of carbon dioxide (CO_2). CCS inputs high energy and the associated risks are unknown. Alternatively, Carbon Capture and Conversion (CCC) can limit risks and costs by converting CO_2 to valuable products while meeting the energy needs of reduction by absorbing light energy with a semiconductor photocatalyst. The photocatalyst will produce electrons and holes to support the reduction of CO_2 and the accompanying oxidation in the reduction mechanism. The focus of our project is to synthesize ethylenediamine surface functionalized reduced crumpled graphene oxide- titanium dioxide (EDA/rGO-TiO_2) catalyst particles and test its ability to reduce CO_2. We used a furnace aerosol (FuAR) method to synthesize the catalyst and tested its functionality by passing a flow of CO_2 and water through a home-made quartz reactor under light radiation with the particles in the reactor. The gas concentrations were recorded using a gas chromatograph (GC) after 12 hours. TEM, SEM, FTIR and Raman spectroscopy were used to characterize EDA/rGO-TiO_2. Analysis showed successful surface functionalization with EDA, crumpling and reduction of GO, and intercalation of TiO_2 in the catalyst structure. The GC showed positive reduction results.

Use of Field-Induced Surface-Organometallic Interactions to Control Selectivity in Rhodium-Catalyzed Organic Reactions

Dylan Barber
Chemistry, Williams College

NNIN REU Site: Stanford Nanofabrication Facility, Stanford University, Stanford, CA
NNIN REU Principal Investigator: Matthew Kanan, Chemistry, Stanford University
NNIN REU Mentor: Craig Gorin, Chemistry, Stanford University
Contact: Dylan.m.barber@williams.edu, mkanan@stanford.edu, cgorin@stanford.edu

A major challenge facing chemists is to control the selectivity of chemical reactions. The common response is to focus entirely on catalyst design to improve yields of desired products. Electric fields generated at the interface of an electrode and electrolyte solution have shown promise as an additional method to control chemical reactions. In previous work, our group showed that Lewis acid-catalyzed rearrangements of epoxides and rhodium-catalyzed carbene insertions favor different products when subjected to interfacial electric fields. We also established that interfacial electric fields can induce surface–organometallic interactions that can change product ratios by more than 100-fold. In this work, we exploit a field-induced TiO_2–Rhodium porphyrin interaction to change the site selectivity of a C–H insertion reaction. Depending on the interfacial charge density, the product ratio in the Rhodium Porphyrin–catalyzed reaction of 1-diazo-3-(3-methoxyphenyl) propan-2-one to 5-methoxy-1*H*-inden-2(3H)-one and 4-methoxy-1*H*-inden-2(3H)-one changes 16-fold, with a 3.6-fold increase in conversion of the starting material. We also investigated the use of different rhodium catalysts and an alternative HfO_2 dielectric. These experiments showed similar effects, indicating that the observed surface–catalyst interactions are not limited to the TiO_2–rhodium porphyrin pair in which they were first observed.

Fabricating Dual-Sided Micro Lenses and High Frequency Talbot Diffraction Gratings Using Binary Masks

Bradlee Beauchamp
Engineering Physics, Rose-Hulman Institute of Technology

NNIN REU Site: Colorado Nanofabrication Laboratory, University of Colorado, Boulder, CO
NNIN REU Principal Investigator: Rafael Piestun, Electrical, Computer and Energy Engineering, University of Colorado Boulder
NNIN REU Mentor: Anurag Agrawal, Electrical, Computer and Energy Engineering, University of Colorado Boulder
Contact: beauchbk@rose-hulman.edu, rafael.piestun@colorado.edu

Binary photomasks are a way of approximating three dimensional structures when using photolithography. Multiple masks are used and the surface of a substrate is etched in discrete steps. The number of masks used determines the number of heights that can be attained. A Fresnel lens was made using this method, and was etched into both sides of a quartz substrate; the advantage of using a phase mask on both sides of a lens is that diffraction effects that take place inside of the medium can be taken advantage of. The two phase masks multiply and can be as effective as one phase mask, and the Fresnel lens was made and tested as proof of this concept. This idea eventually was carried over to make a diffraction grating that uses what is called the Talbot effect. This effect describes the phenomena where light that passes through a periodic grating repeats itself at certain distances termed the Talbot length in the near-field. The frequency of the pattern doubles at a quarter of the Talbot distance. By creating relatively shifted diffraction gratings on either side of the substrate, we effectively create a higher frequency grating than what is possible using standard fabrication methods.

Characterization of Polymer Films on Silicon Photonics Devices for Blood Analysis

Alexandra Benson
Chemistry, Hope College

NNIN REU Site: NanoTech User Facility, University of Washington, Seattle, WA
NNIN REU Principal Investigator: Daniel M. Ratner, Bioengineering, University of Washington
NNIN REU Mentor: James T. Kirk, Bioengineering, University of Washington
Contact: alexandra.benson@hope.edu, dratner@uw.edu, jtk8@uw.edu

Silicon photonic devices employ microscale silicon features as optical guides to direct light in applications such as high-speed telecommunications and biosensing. The microring resonator, an archetypal silicon photonic device, consists of an optical waveguide fabricated in close proximity to a silicon ring. Light at a resonant wavelength dependent on ring dimensions and effective refractive index couples into the ring; in biosensing applications, waveguides are modified using surface chemistry to facilitate selective binding of biomaterials from complex media such as blood. With any biological binding event, a shift in resonant wavelength is detected due to a change in the local refractive index at the waveguide surface. Surface protein fouling of these biosensors has been observed upon use in clinical samples, but growth of zwitterionic polymer films through atom-transfer radical polymerization minimizes non-specific binding events while enabling chemical immobilization of capture elements for biosensing. Here, we develop a reliable protocol for the characterization of these polymer films using AFM to correlate topographical film quality and surface roughness with the ability of modified sensors to inhibit protein fouling. The reproducibility of the polymer film quality is essential for the potential use of these devices in clinical applications, particularly in antibody/antigen binding for performing serologic and phenotypic analysis of biologic samples.

Effect of Reactive Ion Etching on Laser-Annealed Low-k SiCOH Materials

Kris Beykirch
Physics, Corning Community College

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Porous low-κ dielectric films are a potential solution to capacitance-induced delays in the backend of microelectronic circuits. Millisecond laser annealing of precursor low-k materials to temperatures approaching 1200°C is being explored as a potential technique to maintain low-k behavior while achieving other requirements including modulus and etch resistance. In order for these materials to be viable for use in industry, they must be able to undergo common processing such as reactive ion etching (RIE). This project aims to examine the compatibility of laser annealed low-κ SiCOH films with two conventional SiO_2 etches: CF_4 and CHF_3/O_2. Film densification and etch behavior were determined as a function of annealing temperature and dwell time. Samples were prepared under a variety of annealing conditions, ranging from room temperature to 1200°C with heating dwells from 0.75 ms to 2 ms. The data shows that the etch rate is a very strong function of annealing temperature.

Inkjet Printed Interconnects for Multilayer Flexible Electronics

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Inkjet printing is emerging as an efficient and versatile method for the mass production of flexible electronic devices; however, there is a growing need for a method to create multilayer circuits in order to make the devices more compact. The goal of this project is to develop a method to fabricate fully interconnected multilayer circuits at a high rate using inkjet printing. Different from current interconnection strategies relying on material removal processes for forming via holes, the new process involves printing multilayer electronic components separated by printed insulating layers, wherein the via holes are fabricated simultaneously with the insulating layers. Printing a conductive ink directly into the via hole results in the interconnection of electronic components on separate layers. The aim of this research work was to achieve a via hole size of 100 μm or less. Ink containing silver nanoparticles was used for the conducting layers and SU-8 2002 photopolymer was used for the insulating layers. During fabrication, vias with diameters between 65 μm and 100 μm were printed consistently, and the measured resistance of the multilayer interconnects differed little from that of single layer circuits. Bend tests revealed a slight increase in resistance, which stabilized with repeated bending.

Characterization of Single Component Molecular Glass Resists

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Molecular glass photoresists have specific characteristics like small molecular size, the ability to form amphorous films, and high glass transition temperatures, which make them strong candidates for the next generation lithography. As polymeric photoresists are reaching their limits in feature size and line edge roughness, attention has turned to small molecule photoresists like molecular glasses. This research investigated single component resists designed for future use in physical vapor deposition studies. The critical doses, etch resistance rates, and electron beam lithography performance of three molecular glasses, CM-CR3, CM-CR5 and CM-CR6, were evaluated. The contrast curves of CM-CR3, CM-CR5 and CM-CR6 did not have a steep slope, however the critical doses were identified as 150 mJ/cm^2, 300 mJ/cm^2 and 250 mJ/cm^2 respectively. All three molecular glasses displayed a comparable etch resistance to poly(4-hydroxystyrene) using CHF_3/O_2 as the etch gas. The electron beam lithography performance was evaluated using scanning electron microscopy. CM-CR6 was identified as the most suitable molecular glass photoresist candidate.

Developing Nanoscale Electrodes for Sensitive Detection of Brain Cell Activities

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Vertical nanopillar electrode arrays have garnered much attention due to applications in the study of the electrical behavior of neurons. Previous methods for measuring neuronal activity include the use of planar multielectrode arrays (MEAs); however, neuronal mobility and inefficient neuron-electrode interactions on flat substrate surfaces make it difficult to monitor the activity of specific neurons over extended periods of time. Vertical nanopillar arrays serve as a neuron traps by effectively pinning the neurons and also offer a non-invasive measurement technique, thus allowing for long-term study. In this work, novel MEA devices are designed and fabricated on quartz and glass substrates using standard photolithography methods. Vertical nanopillars of varying diameters (200-600 nm) and material compositions (Au, Pt and IrO_2) are then electrodeposited on the MEA devices. Optical microscopy and scanning electron microscopy are used to confirm the quality and morphology of the devices throughout processing. The devices fabricated here have the potential to serve as high sensitivity probes for detecting membrane potentials at the synapse level which will help in understanding the long term behavior of neuronal circuits.

Infrared Filtering via Sub-Wavelength Gratings for Hyperspectral Imaging

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Hyperspectral techniques can vastly improve object discrimination capabilities in thermal imaging. This can contribute to advancements in tracking climate change, night vision on the battlefield, and chemical and biological sensing. In hyperspectral imaging, the electromagnetic spectrum is recorded for every point in an imaging plane, providing a “fingerprint” for different objects. To obtain the necessary information for creating these images, narrowband filters are required. An attractive means of achieving narrowband filtering is the Fabry-Perot etalon, which provides 100% transmittance when a standing wave is established between two non-absorbing mirrors. High index-contrast gratings (HCGs) have shown promise for realizing lossless reflectors for use in these systems. We report greater than 88% reflectance in the long-wavelength infrared (LWIR, 8-12 μm), a region common in thermal imaging, using a suspended silicon/air HCG. We used finite element analysis to optimize the design and structure fabrication was based on a silicon-on-insulator platform. Fabrication included photolithography and reactive ion etching (RIE) to define the gratings, and wet etching to suspend them. We have characterized a C_4F_4/SF_6 RIE, which provides improved grating sidewall profiles over previously used H_2/HBr etch chemistry. Fourier transform infrared spectroscopy was used to measure the structure response, which exhibits good agreement with simulation.

Silver Nanoplates: Structural Stability and Optical Properties

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Silver nanoplates have attracted significant attention in the nanomaterials community for their numerous possible future uses. These nanoparticles are classified as 'plates' because they have high aspect ratios. Their edge lengths can be made to be between 30 and 500 nm and they are typically triangular in shape. Smaller nanoplates are produced in an ethanol system and are relatively stable. These plates exhibit interesting optical properties because they are smaller than the wavelengths of incident light. In water, they are typically unstable and selectively etch at the corners. This selective etching is accompanied by a drastic color change that promises strong sensing applications. Stability is key for other future applications of these electrically conductive nanoparticles such as metallic inks and flexible electronics. Stabilizing these nanoparticles may be achieved with a thin gold coating; a technique achieved with nanocubes. The goal of this project was to synthesize silver nanoplates and characterize their optical properties in relation to size, shape and local environment. These changes can be seen visually through a color change and can be quantified through UV-vis spectra. Understanding this 'building block' of nanoscience is a key step towards utilizing metallic nanomaterials in more intricate applications.

Low-Temperature Cu Segregation and Oxidation in Microwaved Ag-Cu Alloys

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Microwave annealing presents itself as a great processing technique due to its low cost, efficiency, and short heating times. Samples of a Ag-Cu alloy of 13% Cu are annealed in a microwave cavity for up to 200 seconds, with a maximum temperature of 80°C. Rutherford backscattering spectrometry indicates copper segregation to the surface. Oxygen resonance analysis and x-ray diffractometry (XRD) show that a thin self-passivating copper oxide layer begins forming on the surface at 40 seconds and completes at 80 seconds. Four-point probing and XRD suggest that subsequent annealing results only in additional Ag grain growth.

Development of Platinum@Reduced Graphene Oxide Catalyst for Fuel Cell Applications

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A possible replacement to the current internal combustion engine with its low emissions and high energy conversion would be the proton exchange membrane fuel cell (PEMFC). In the anode portion of the PEMFC, a catalytic electrode consists of a conductive metal@carbon matrix, responsible for hydrogen gas oxidation. The focus of the project is to optimize the efficiency of the catalyst, synthesizing Platinum@reduced graphene oxide (Pt@rGO) matrix using two dispersing agents: Polyvinylpyrrolidone (PVP) and Nafion ionomer. Dispersed Pt nanoparticle sizes from each sample were calculated with the diffractometer. Samples' performances were measured with cyclic voltammetry (CV). From CV data, a small amount of PVP resulted in Pt aggregation with an active Pt surface area of 24.14 m^2/g. The addition of PVP and of low concentration Nafion ionomer separately corresponded to an active Pt surface area of 28.50 m^2/g and 40.85 m^2/g, respectively. Still, the efficiencies from not yet optimized parameters of Pt@rGO are not as high as conventional Pt@carbon black. Currently, optimal concentrations of various dispersing agents on Pt@rGO are being explored.

MOSFET: Fabrication Process and Performance Analysis

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Metal-Oxide Semiconductor Field-Effect Transistors (MOSFETs) are commonly found on microchips in modern electronics and typically serve important roles as switches. Studying transistors and optimizing their structure results in more efficient electronics. The focus of the project was to fabricate efficient MOSFETs and to measure their performances using a Semiconductor Parameter Analyzer (SPA). The SPA generates current-voltage graphs that allow for performance measurements and quantitative analyses. The MOSFETs were created using the trench method, which consisted of applying various etching, lift-off, and deposition steps to processed wafers. These wafers were grown with a 2 nm stop etch layer of indium phosphide, which is a film that slows or prevents certain etchants from penetrating the surface. Since the stop etch layer was so thin, the etchant tunneled through the gate regions' indium phosphide. It was important to determine the optimal gate-region wet etch time because insufficient time resulted in devices that experienced short circuits, while excessive time resulted in lower device performance. Discovering a finite time to wet etch through 2 nm of indium phosphide will help improve the chances of fabricating high-performing MOSFETs in the future.

An Experimental and Theoretical Investigation of Ultrasound Transmission in Bubbly PDMS Phononic Crystals

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Phononic crystals are two- and three-dimensional structures with a periodic arrangement of two or more materials with different acoustic properties. Depending on the size, structure, and properties of the constituent materials, meta-materials with interesting acoustic properties can be formed. In this study, the transmission of ultrasonic waves through polydimethylsiloxane (PDMS) films with entrapped air bubbles are investigated. Our presentation highlights the ultrasonic transmission as a function of the dimensions, separation, and arrangement of the air bubbles. We reproduced previously published data using two different theoretical models that describe ultrasonic transmission in air-PDMS crystals: (1) a simple scattering model for a series of partially reflective thin films, and (2) the code MULTEL, which provides a full transmission solution based on Multiple Scattering Theory. We then used these models to predict the performance of new crystalline structures. To create these structures, we first fabricated arrays of micron-scale pillars on a silicon wafer. PDMS layers were then cast on these pillar templates and stacked to form air bubble arrays with two- and three-dimensional periodicity. Finally, we measured the ultrasonic transmission through the films using a transducer/receiver setup in a water bath and compared it to the theoretical results.

Growth of Graphene on Various Substrates

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Graphene is a single layer of graphite; its unique properties consist of chemical stability, high tensile strength, flexibility, and high thermal conductivity. These properties make graphene suitable for future applications such hydrogen storage, lighter prosthetics, and flexible electronics. Past methods of graphene preparation such as exfoliation are efficient for lab purposes, but are not suited for mass production. With applications in mind, suitable substrates and methods for large quality graphene growth are necessary. This project focused on how various substrates affect graphene growth and which methods of graphene growth are suitable for different substrates. Graphene was grown by the following methods: simple chemical vapor deposition (CVD), hot filament CVD, and radio-frequency plasma CVD. The methods were selected because they provide the option to use various substrates under unique conditions. From these methods, graphene growth was attempted on the following substrates: copper, 3C-silicon carbide on silicon, nickel, nickel chrome, and nickel films on 3C-silicon carbide. These substrates were selected due to their properties of strength, ductility, and resistance to corrosion and heat. The substrates were characterized using scanning electron microscopy and Raman spectroscopy. Raman results have confirmed graphene on nickel films on 3C-silicon carbide. Raman results to verify graphene on the other substrates are ongoing.

Investigation of Microfluidic Integration in Magneto-Nanosensor Based Protein Biomarker Detection

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The use of magnetic nanoparticles in conjunction with a spin-valve type GMR (giant magnetoresistive) sensor provides a method for the detection and quantification of femptomolar concentrations of proteins in biological samples. The magnetic nanoparticles act as a magnetic tag for proteins which allow the quantification of targeted proteins. Recent developments in the lab's custom microfluidic integration approach with the spin valve sensor array allow for simultaneous testing for multiple samples on a single chip and a variety of proteins within a given sample. In this work, testing is being conducted to study the distribution of magnetic nanoparticles following the completion of microfluidic assay experimental procedures. Specifically, the final locations and local densities of the magnetic nanoparticles and the presence of washing buffer fluid following the assay are being compared to the geometry of the microfluidic channels. The comparison of these patterns may lead to improvements in the efficiency and reproducibility of the bioassays. A SEM is being used as the primary source of images in this study. Some potential applications for this technology include multiplexing of surface interface sensors within automated point-of-care diagnostic devices.

Ion Transport Through Porous Graphene

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Graphene is a 2D carbon material that is only one atom thick with exceptional strength and remarkable gas separation properties. Graphene membranes have great potential for applications in DNA sequencing, desalination and water filtration, as well as lab on a chip processes. The focus of this project is to investigate the potential of graphene membranes for liquid separations. A microfluidic device was designed and fabricated to test graphene's separation properties in liquids. CVD graphene was freely suspended over a thin copper foil and attached to a PDMS microfluidic substrate. Suspended graphene was fabricated via standard photolithography while a PDMS substrate was fabricated via soft lithography techniques. To observe the permeability of graphene membranes, pressurized deionized water was introduced onto the underside of a graphene membrane through a microfluidic channel and the graphene membrane deflection was measured via atomic force microscopy in air. Future work includes electrical testing of water and ionic transport across porous monolayer graphene membranes.

Cisplatin-based Metal Organic Framework Nanoparticles for Target Drug Delivery and Tumor Imaging

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Nanoscale metal organic frameworks particles (NMOF) are nanoparticles composed of an amorphous framework constructed from an organic linker ligand and a metal ion. These nanoparticles are an excellent candidate for use in drug delivery due to their biodegradability, tunable size and high loading capacity. In this study, we synthesized novel NMOFs based on the anti-cancer drug cisplatin with high payload (83%). A targeted near-infrared imaging probe was also incorporated into this nanoparticle to achieve imaging capability and targeted drug particle delivery. The targeted delivery of this therapeutic imaging probe was evaluated both *in vitro* and *in vivo*, and the anticancer efficacy was demonstrated on cancer cells *in vitro*.

System Automation for High Throughput Biosensor

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Photonic crystal (PC) microcavities have demonstrated the highest sensitivities among label free chip based optical biosensors. These high sensitivities coupled with the study of binding kinetics have important implications in the fields of biomarker and drug discovery for pharmaceutical industries. Binding affinity (ΔG) and association constant (Ka) can be used to effectively characterize biomarkers in a simple and cost effective fashion. To economically determine these constants, an automated data collection and analysis system would have to be created. Here, we demonstrate the methodology of calculating Ka and ΔG based off of experimental data received from L13 and L55 silicon-based PC micro-cavities that have previously demonstrated sensitivities down to 50 femto-molar. Due to problems and time constraints, actual biosensing was not able to be performed. Proof of the functionality of our newly created automated system is determined using chemical sensing of sugar water using different molar concentrations. Static and dynamic testing setups, along with collective pros and cons, will also be discussed. Finally, a basic overview of our PC microcavities is explained.

Fabrication of Accelerometers using Paper MEMS Substrates

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The purpose of this research project was to make an accelerometer using micro electro-mechanical systems (MEMS) using paper as the substrate. Paper was chosen as the substrate because it is so inexpensive, easy to fabricate, and does not require a cleanroom. After constructing the design we painted a small size piezoresistive carbon ink and a silver conductive ink on it. Cantilevers were created from the paper substrate to compare the relationship of the applied force and the change in resistance of the MEMS, and similarly the connection between the applied force and the capacitance of the MEMS device. Our results indicated a linear relationship from the graphs that we obtained from our experiments. Next we related the similarities between the cantilevers and created an accelerometer using the same materials as the initial cantilevers. By correlating the difference between the force and capacitance, Ohm's Law was used to acquire the voltage and relate that to the acceleration. Using an integrated circuit applied to the accelerometer we converted the capacitance into a voltage, then associated that with an acceleration. After testing and enhancing the accelerometer, we were able to successfully find the G-Force.

Nanoscale High-Speed Transparent Electronics Using E-Beam Patterning of Zinc Tin Oxide Thin Film Transistors

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By utilizing wide band gap semi-conductors, such as zinc tin oxide, it is possible to fabricate transparent thin film transistors. These transistors are needed for many new applications in heads up displays, invisible RFID tags, and other transparent technologies. As the gate length of a transistor is reduced the current speed increases, thus increasing circuit performance. The focus of this project is to miniaturize the gate length of zinc oxide based transistors to below 100 nanometers and characterize the performance of these transistors as a function of their gate length. A process compatible with e-beam lithography was developed to yield channel lengths down to 20 nanometers. Currently, electrical testing is being performed on these narrow gap electrodes.

Silicon Nanophotonic Add-Drop Filters Based on High-Q Square Resonant Cavities

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Silicon nanophotonic circuits can employ photonic devices to receive, manipulate, and transmit optical signals for information transfer. They have the potential to be integrated within computer chips, with the advantage of providing communication links with smaller I/O footprint, wider bandwidth and lower energy consumption than copper interconnects in current, state of the art microelectronic circuits. One key device in photonic circuits is the add-drop filter, which can perform wavelength-division multiplexing (WDM). An add-drop filter can be made using a single microring placed in between two waveguides. The ring will be resonant at a particular wavelength, at which a guided mode passing through one waveguide will be dropped into the receiving waveguide. However, microrings resonators' curved geometry requires layouts not compatible with standard, Manhattan-geometry CMOS circuits. In this work, we investigate square microcavities that can support high *Q* resonances yet fit into a standard CMOS process. Single square cavities send resonant light to all four ports of the filter by symmetry, an undesirable feature. A pair of square resonators, operated in push-pull mode, can emulate a ring's behavior, and produce a single-drop port filter. The goal of this project is to demonstrate such an add-drop filter in the silicon-on-insulator (SOI) platform.

Area-Selective Atomic Layer Deposition (ALD): New Recipe Development

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Atomic layer deposition (ALD) allows thin films to be deposited layer-by-layer onto a substrate by a sequential flow of gaseous chemical precursors. These precursors react with the substrate surface in self-limiting reactions and then can be repeated until the thin film reaches a desired thickness. Area-selective ALD deposits material onto one substrate while leaving another substrate unaffected. This has many applications in device manufacturing. The focus of this project is to develop a recipe to selectively deposit tantalum nitride (TaN_x) on one surface (SiO_2), while limiting the growth on another surface (Cu). We are interested in thermal TaN_x, using pentakis(dimethylamino)tantalum (PDMAT) and ammonia (NH_3) as precursors. From previous studies, we know that PDMAT forms strong bonds with the substrate surface. We have decided to add an 'etchant', dimethylamine, $(CH_3)_2NH$ (DMA) to the TaN_x ALD recipe to drive the reaction backwards, selectively favoring the surface on which PDMAT does not prefer to bond (Cu). We investigated DMA concentrations, DMA step placement, DMA dose times, and sub-saturation of PDMAT doses for short TaN_x ALD deposition. Analysis of the films was done using spectroscopic ellipsometry for TaN_x films on SiO_2 substrates and wavelength-dispersive x-ray spectroscopy (WDX) for TaN_x films on both substrates.

Engineering Three-Dimensional Biological Scaffolds Using a Modified Rotary Jet Spinning System

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Protein fibers with nanoscale diameters comprise the extracellular space in tissues and organs in the body. Current tissue engineering approaches often fail to recapitulate the three-dimensional nanoscale geometry of extracellular matrix fibers. Here, we have designed and developed modifications to a rotary jet spinning (RJS) system for fabricating nanofibers. Traditionally, the RJS produces two-dimensional sheets of polymer nanofibers at high speeds by solution extrusion through a perforated reservoir. Due to the nanometer thickness of the elongated polymer droplets, the nanofibers quickly dry and solidify and then are collected on a mandrel. The focus of this project is to engineer an automated nanofiber production and mandrel collection system in order to (a) easily create anisotropic scaffold tissue and (b) generate small three-dimensional basic organ structures. The RJS system was constructed with multiple points of actuation for precise control, a computer program that allows for various parameter inputs to alter the fabrication process, a specially made support structure, and a custom designed interfacing circuit to allow for digital controls over high-voltage inputs and outputs. Currently, the RJS system is nearing the completion of its engineering process. With these modifications, we will be able to replicate the three-dimensional nanostructures of tissues and organs.

Nanocharacterization of Wood Fibers in Cement

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Fiber-reinforced cement is one current way to aid the internal curing of concrete and prevent both shrinkage and cracking. Fiber is a novel agent in the curing of cement and has been previously thought of as an inert reactant in this process. However, calorimetry tests at early stages of cement curing indicate that this fiber is reacting with the system in such a way that fiber is not inert. The focus of this project is to determine whether the fiber is acting as a nucleation site which accelerates the formation of hydration products, if it is acting as a semi-permeable membrane that aids the movement of pore solution ions, or possibly both. By observing the chemical and physical interactions at the nanoscale level through a scanning electron microscope (SEM), x-ray photoelectron spectroscopy (XPS), inductively coupled plasma mass spectrometry (ICP), and atomic force microscopy (AFM), these tests will indicate certain interactions which allows for further optimization of the fiber's properties.

Voltage-tunable Plasmonic Metamaterials Based on Stark Tunable Intersubband Polaritons

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The project explores ways of producing voltage-tunable plasmonic metamaterials. By combining plasmonic metamaterials with intersubband transitions in $In_{0.53}Ga_{0.47}As/Al_{0.48}In_{0.52}As$ coupled quantum well heterostructure, we fabricated and tested devices that have optical response sensitive to applied bias voltage. The plasmonic metamaterials consist of an array of sub-wavelength plasmonic elements, resonant in the mid-infrared. The plasmonic structures were fabricated using electron beam lithography (EBL) with a largest feature of 1.544 μm and a smallest feature of 420.3 nm. The devices were characterized using Fourier-Transform-Infrared-Spectrometer-based (FTIR) reflection measurement. Resonance matching between intersubband transition and plasmonics resonances was confirmed by observing polaritonic splitting of absorption peaks in reflection spectrum. Experimentally, applying 5.5 volts of DC bias achieved 71 nm of wavelength tuning around 8 μm wavelength.

Understanding Magnetic Plasmon Mode Mixing Using Electron Energy Loss Spectroscopy

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Circular clusters of gold nano-particles that support collective magnetic plasmons show potential for use in sub-wavelength optical circuitry as well as artificial conjugated molecules [1]. To induce a magnetic plasmon we started with a collection of hexagonal particles each supporting spectrally overlapping electric dipole modes. Stimulating each electric dipole mode tangentially to the effective circle of particles results in a (many) split-ring resonator. The alternating current around the ring of particles produces a characteristic magnetic dipole that oscillates in phase with the electric polarizations. In order to utilize magnetic plasmons in application a detailed understanding of the mode mixing involved must be developed. Because nano-particle clusters that support magnetic plasmons are composite, their mode structures are inevitably complex. This project examines the mode mixing of conjugated hexamers using Discrete Dipole Approximation simulations of Plane-Wave Scattering and Electron Energy Loss Spectroscopy. Using the localized field of the e-beam we will describe the Fano-like interferences visible in the complex extinction spectra of various magnetic plasmon structures.

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Silicon Nanowires for Optical Light Trapping in Solar Cells

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Control of surfaces is key to boosting a solar cell's conversion efficiency through reduction of reflectivity and enhanced electrical performance through carrier confinement. Inexpensive surface texturing is commonly used to minimize the reflection losses. However, this method is dependent on the refractive index of the semiconductor, and quickly reaches an absorption limit. Nanowires with sub-wavelength dimensions offer great potential for decreasing reflectance beyond the bulk limit. These attributes are shared with other sub-wavelength scaled features, but nanowires offer the unique advantage for separation of light absorption and carrier transport due to the confinement of electrons in two dimensions. Our goal is to fabricate functioning Si nanowire solar cells on the sub-wavelength length scale in order to (a) observe reflectance of nanowire arrays and (b) study the electrical characteristics of nanowire devices. The first part of the project was focused on tuning the electron-beam lithography process used to develop the nanowire grid layout. Etching is conducted by the Bosch process and amorphous Si is deposited by PE-CVD as passivation. These processes result in well-controlled nanowire structures, measurements of which provide an understanding of light trapping in nanowire arrays and permit integration into a test solar cell for electrical performance measurements.

Fabrication of Nanofluidic Devices for DNA Confinement

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Obtaining sequence information from entire genomes is highly desirable for many biological applications. However, genomic DNA naturally exists as tangled coils making it difficult to analyze. But if the DNA could be confined to a nanochannel with dimensions similar to that of the persistence length of the DNA, it would exist in a fairly linear configuration, making the DNA amenable to various forms of sequence analysis such as genomic mapping. Therefore, our objective was to fabricate nanofluidic devices that would allow for efficient confinement of genomic DNA. To limit DNA sticking to the channel walls an inherently hydrophilic material, fused silica, was used as the device substrate. After overcoming many fabrication hurdles, we successfully fabricated the nanofluidic device. However, DNA sticking to the nanochannels proved to be a significant issue during device loading. Scanning electron microscopy images of the nanochannels indicated that channel roughness was likely the cause. The fabrication process was further refined, especially nanochannel etching, to minimize this roughness. Once a robust fabrication process is developed, we can continue our investigation to understand and model how the confined DNA behaves, which will both help enable large-scale use of these nanofluidic devices and validate theoretical models of polymer physics.

Poly(3-alkyldithienothiophene): Synthesis, Structure and Optical Properties

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Organic electronics is a growing area of research that investigates the properties and applications of conjugated polymers and semiconducting small molecules. Devices made from organic materials have the potential to be flexible, inexpensive to process, and lower weight as compared to their inorganic counterparts. Organic photovoltaic (OPV) devices are researched for their potential properties to become a low-cost alternative to silicon-based photovoltaic devices. Poly(3-hexylthiophene) (P3HT) is one of the most successful homopolymers due to its semi-crystalline structure, strong light absorption properties, and high charge carrier mobility. However, the short-circuit current density (J_{sc}) and open-circuit voltage (V_{oc}) of P3HT devices are limited due to a wide HOMO-LUMO gap and high HOMO energy level. For these reasons, quinoid polymers are being developed to control the energy levels. Since the quinoid resonance form is lower in energy than the aromatic form, stabilizing the quinoid form will effectively reduce the band gap of related conjugated polymers. In this context, regioregular alternative copolymer of 3-thioalkoxythiophene (TAT) and 3-alkylthiophene (AT) : *alt*-P3TAT-*co*-3AT has intriguing structure because the repeating unit can be transformed to 3-alkyldithienothiophen (3ADTT) as a quinoid repeating unit. The preparation method and regioregularity of *alt*-P3TAT-*co*-3AT and P3ADTT, also their optical properties are discussed.

Determination of Strength Degradation Mechanisms of Native Oxide on Silicon Nanostructures

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Identifying the strength of micro- and nanoelectromechanical systems (MEMS and NEMS) is essential for effective designs. The fact that nanoscale strength does not scale from macroscale strength it is required to test single crystal structures individually. Research has shown that the growth of oxide in silicon nanostructures leads to a decrease of strength, therefore increasing the likelihood of failure. To understand the correlation between silicon strength and oxide growth the strength of silicon nanobeams were tested over a span of five weeks allowing native oxide growth. Failure tests of the beams were taken weekly using an atomic force microscopy (AFM), which measured the deflection of the AFM cantilever and the displacement of the piezo. A reference cantilever was used to find the stiffness of the AFM cantilevers used for failure tests. The beam's failure stress was derived using its failure force in a finite element model (FEM).

Zinc Oxide Based Solar Cells for Self-Powered Smart Window Application

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Integrating electrochromic films to existing business and residential windows is proposed as a way to reduce the building power consumption by cooling the structure in a passive manner. A voltage can be applied to the electrochromic stack, thereby increasing its opacity and blocking infrared radiation from the sun from entering the structure and heating the interior. Zinc oxide (ZnO) based solar cells are promising candidates for supplying such a voltage, as ZnO possesses a wide bandgap, is visibly transparent in thin film microstructures, and forms a Schottky barrier with a certain variety of metals. In theory, a device containing a ZnO-metal Schottky diode should be capable of driving an electrochromic stack. In an attempt to fabricate such a device, different contacts were deposited onto ZnO thin films and the resulting current/voltage characteristics were measured.

Deposition of Immobilization Layers for Extremophile-Based Biosensors

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Biosensors composed of biomolecules and electromechanical components have enabled new sensing modalities for chemical sensing, pathogen detection and disease therapy. Traditional biosensors are silicon-based, but silicon has a known limited radiation lifetime. Gallium nitride (GaN), however, is radiation-hard and shows potential for use in biosensors to detect radiation. To support the development of a biosensor based on GaN and the radiation-tolerant extremophile bacteria *Deinococcus radiodurans*, we study the attachment of various interfacial layers to GaN. More specifically, we attach interfacial organosilane immobilization layers to GaN using molecular layer deposition and liquid deposition. Die-level photolithography and lift-off are used to define the shape of the immobilization layer, and we use surface water contact angle and ellipsometry to characterize the attachment properties of these immobilization layers on GaN thin films. Optimization of this attachment will allow for long-lasting radiation detectors for applications such as medical radiation therapy and deep space exploration.

Fabrication of All-Aluminum *n*-Type Silicon Solar Cells

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One of the fundamental bottlenecks for silicon solar cells in reaching terawatt scales is the scarcity of Ag. Furthermore the price of Ag has been rising sharply. We propose Al as a potential substitute for Ag. Generally *p*-type silicon wafers are used in solar cells, however *n*-type wafers have the potential for high efficiency solar cells and are more suitable for all-Al contact solar cells. Surface passivation on the p^+-emitter requires a different technique from an n^+ emitter. In our process, there are four major steps. First, random texturing was performed on both sides of a wafer in order to reduce the reflectance. Second, diffusion processes were applied to the wafers to fabricate the *p-n* junction and the back surface field. Third, Al was deposited on both sides of the wafer as the metal contacts. Finally, thin-layers of Al_2O_3 and SiN_x were coated on the surface for passivation and anti-reflection. In addition, annealing was applied to the wafer to improve the contacts between metal and silicon. After each step, the wafer was characterized to monitor the process.

Developing Bioinspired Slippery Coating on Industrial Steels

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Creating an omniphobic coating on industrial metals that can repel various liquids and solids would have numerous industrial and medical applications, yet the development of such a coating has been very challenging. Inspired by the insect trapping mechanism of a pitcher plant, a novel repelling surface was developed, which was termed as "Slippery Liquid-Infused Porous Surfaces" (SLIPS). SLIPS is consisted of chemically functionalized micro/nanostructured substrate and infused with a lubricating liquid. In this project, SLIPS on industrial steels were developed which showed promising results for industrial uses. The resulting SLIPS-treated metal showed excellent liquid repellent properties against a broad range of fluids, including water and oils, as well as complex fluids, such as blood. Since the micro/nanotextures are mono-lithographically integrated with the metal surfaces, our SLIPS coatings demonstrate excellent robustness against multiple physical damages. Additionally, the application of SLIPS on metals of any geometry was demonstrated including flat surface, sphere, and pipe tube. The ability to apply omniphobic slippery coatings on industrial steels would enable a broad range of industrial and medical applications including multi-functional coatings for anti-icing, anti-corrosion, anti-scaling, friction reduction, and anti-fouling purposes.

Development of Microfluidic Devices for use in Immunophenotyping

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Immunophenotyping presents significant promise in the diagnosis and prognosis of immune system disorders. While standing as a means of detection of diseases including HIV/ AIDS, tuberculosis and sepsis, the available methods of immunophenotyping are inefficient and lacking in selectivity. The current convention measures cytokine production in mononuclear cells of the cardiovascular periphery. The overall reactivity of immune cells may be determined, rather than the specific phenotypes of the reactive cells of interest. Microfluidic devices may present the solution to the array of limitations of existing immunophenotyping technology. Through the integration of a high-porosity, polydimethylsiloxane (PDMS) microfiltration membrane (PMM), with a microfluidic microfiltration platform, microbead filtration may be used to achieve antigen-specific cellular isolation. The PMM was fabricated via semiconductor microfabrication techniques including traditional lithography and RIE. The silicon molds for components of the microfiltration platform were fabricated using photolithographic techniques, followed by deep RIE (DRIE). The PDMS components were then layered to construct a complete device for use in microfiltration and subsequent cellular simulation and optical detection. A chemiluminescence assay will allow for highly sensitive subpopulation identification from a blood sample. The development of these microfluidic devices will drastically reduce time, costs and inaccuracies of immunophenotyping, thus yielding more efficient detection, evaluation, and treatment of disorders.

Cellular Migration on Curved Substrata

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Recent studies have shown that the topographical and mechanical properties of the structure a cell adheres to are important factors in determining cellular response. Specifically, cells orient along micro/nano-scale grooves of the extracellular matrix (ECM) that provide a bidirectional cue for migrating cells. Advances in fabrication techniques of biomaterials have led to strong control over micromechanical and environmental properties such as local rigidity and curvature of the ECM components [1]. This research focuses on investigating the response of migrating cells on substrate curvature. Using UV-assisted capillary lithography techniques, sub-cellular sized arrays with varying radii of curvature were fabricated containing the critical curvatures and patterns that trigger cell response. We hypothesize that cells react to micrometer range topographical features with variable range of surface curvature. To investigate this, CHO cells were cultured on substrate with different radii of curvature as a model system. From time lapsed live cell imaging, the results demonstrated more explicitly that cells polarized along the direction of topographic feature and moved bi-directionally in circled tracks of topographic feature.

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Fabrication of "Barcode" Nanowires for Multiplexed Detection in Biological Assays

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"Barcode" nanowires, composed of multilayers of gold (Au) and nickel (Ni), provide great flexibility in multiplexing studies, from antibody labeling to cell detection in biological assays. Here, two types of distinct barcode nanowires were fabricated by sequential electrodeposition of Au and Ni. These wires, one Au-Ni-Au and one Au-Ni compositions, were characterized by vibrating sample magnetometry (VSM) to have parallel coercivities of 212 and 229 Oe, respectively, with distinct signatures of coercivity versus angle. Dimensions of the nanowires were measured by scanning electron microscopy (SEM), and the concentrations of nanowires in aqueous solutions were determined using the saturation moment measured on the VSM. Two types of barcode nanowires were successfully conjugated with antibodies that were specific to two different cell lines, one cancerous (A549, human lung carcinoma cells) and one non-cancerous (Human Foreskin Fibroblast cells). Bright field, reflectance, and fluorescence optical imaging techniques were used to observe successful nanowire-tagging of these cells. In short, barcode nanowires have much promise for multiplexed detection of cells.

Effects of Cellular Architecture on MDA-MB 231 Breast Cancer Cell Motility

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Over 200,000 women living in the United States will be diagnosed with breast cancer this year. Of those whose cancer metastasizes, wherein the cells migrate away from the initial tumor, only 23% will survive. Cellular mechanics and architecture can drive a wide range of cellular behaviors such as contractility and proliferation. Here, we assessed the role of cellular architecture in breast cancer motility. MDA-MB 231 breast cancer cells were micropatterned into two sizes of four shapes. We investigated cytocellular architecture, measured lamellipodia extension as a function of that architecture, and quantified cellular invasion into a collagen gel. Results suggest that cellular architecture plays a role in determining the likelihood of tumor cell metastasis.

Microfluidics for the Study of Breast Cancer

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Early diagnosis and treatment are a cancer patient's best chance of survival. To that end, microfluidic systems show great promise for developing point of care diagnostic technologies and quick evaluation of treatment options. Microfluidic systems allow precise manipulation of cells in a controlled environment. They can be cheaply and easily fabricated using standard soft lithography techniques such as replica molding. Microscale systems use smaller sample and media volumes and provide fast results. The focus of this project was to determine the time for a known cancer drug, Tamoxifen, to have an observable effect on MCF-7 breast cancer cells in a microfluidic device. In a previous study using a traditional microarray of wells, MCF-7 cells dosed with Tamoxifen at approximately 20 μM showed 0% viability after six days. For this project a microfluidic device was fabricated using PDMS with two identical 5.95 μL experiment and control chambers separated by a central channel and bonded to a glass slide. MCF-7 breast cancer epithelial cells were grown in each chamber. Just prior to the introduction of Tamoxifen, media began flowing through the central channel to prevent diffusion between the chambers. One chamber was dosed with Tamoxifen at 20 μM and cell viability in the chambers was compared over time.

Thermodynamic Control of Lead Content in the Piezoelectric Thin Film

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Recently, piezoelectric thin films have been attracted as a component for low voltage MEMS applications. Lead-based perovskite materials are widely used because of their excellent ferroelectric and piezoelectric properties. On the other hand, the volatility of lead creates difficulties in the deposition process, because high temperature annealing process is required for prerovskite phase development. Conventionally, excess lead is added to thin films in order to control lead content during high temperature processing. However, it is still difficult to precisely control the stoichiometry of the piezoelectric thin film, since proper amount of excess lead depends on deposition process or conditions. In this study, lead composition control is being pursued in piezoelectric thin film via thermodynamic, rather than kinetic control. Post annealing is being conducted for lead deficient piezoelectric thin films in a PbO furnace. This method should enable to deposit optimized piezoelectric thin films. Initial experiments were conducted to deposit PbO on an Al_2O_3 substrate, which doesn't react with lead chemically, to confirm deposition rates. After these initial experiments, work will be conducted on Pb(Zr,Ti)O_3 thin film.

Design of Synthetic Protein Membranes Using Droplet Microfluidics

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Cell-free protein synthesis incorporated within droplet microfluidics allows for the design of simple biomimetic membranes, potentially overcoming some of the major shortfalls of functionalized nanoparticles. Our collaborators at New England BioLabs developed a technology that utilizes the essential cellular machinery of *E. coli* to create synthetic proteins and protein complexes, which can be designed on the nucleotide level. These synthetic proteins, attached to the interface by a trans-membrane protein segment, may overcome the denaturation commonly seen when binding proteins to solid surfaces and behave more like natural membrane proteins. The focus of this summer's work is to better understand these protein membrane droplets and develop droplet systems for potential applications. We are currently investigating oil drops coated with streptavidin, a femtoliter sensitive biotin-binding protein, to measure droplet-bound protein activity and explore droplet interactions with cells.

Improving Lithium Ion Battery Performance with Dopant Substitution

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To allow widespread utilization of electric vehicles, current energy storage technologies need to deliver high capacity, good rate capability and long cycle life. Nanostructured lithium ion battery cathodes composed of lithium, manganese, nickel, and cobalt (e.g., $Li_{1.2}Mn_{0.53}Ni_{0.13}Co_{0.13}O_2$) demonstrate an excellent capacity greater than 200 $mAhg^{-1}$. Although these layered structures show promising electrochemical characteristics, they suffer from voltage fade upon cycling. The goal of the current investigation is to study the effect of dopants in order to reduce or eliminate voltage fade. The cathode material was produced via spray pyrolysis and then annealed at 800-900°C for two hours. Powder x-ray diffraction measurements were carried out to verify the crystal structure of the cathode material, and scanning electron microscopy was used to characterize the morphology. Electrochemical testing of the materials was performed in 2032 type coin cells, which were fabricated in-house. Charge and discharge tests were performed to test the voltage fade, cycleability and rate capability of the materials. Parallel to these measurements, impedance spectra were recorded to understand effect of dopants on solid state diffusion. With these results, we hope to gain a better understanding of the voltage fade phenomenon of these materials to allow commercial implementation in electric vehicles.

Crumpled Graphene Oxide Nanostructures for Advanced Water Treatment Technologies

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Currently, over three million people die annually from water-, sanitation-, and hygiene-related diseases. Furthermore, according to the World Water Council, 3.9 billion people are expected to live in areas with deficient and unsanitary water supply by 2030. This global crisis calls for water treatment technological advancements, and based on the state of the art, will be increasingly underpinned by engineering/application of nanoscale materials. Our project's aim is to develop an efficient aerosol-based technique to synthesize crumpled graphene oxide (CGO) nanocomposites for enhanced water purification applications. Specifically, we aim to (a) synthesize and characterize two types of CGO nanocomposites, CGO-TiO_2 (as a high performance photocatalyst for pollutant degradation) and CGO-magnetite (as a monomeric self-assembling component of a robust and magnetically manipulatable thin-film membrane); (b) examine CGO nanocomposites' water-stability under different water chemistries (such as pH). UV-vis was used to examine light absorption of CGO nanocomposites; scanning electron microscopy was utilized for size and morphology measurement; and dynamic light scattering and electrophoretic light scattering were used to test nanoparticle size and zeta potential, respectively. Our results indicate an inverse relationship between pH and mean nanoparticle size; and solutions with pH > 3 enable CGO stability (zeta-potential < -30 mV).

Preparation of Transparent Conducting $CuAlO_2$ Foils

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Transparent conducting oxides (TCOs) are semiconductors that allow for transparent electrodes in electronic devices. Most TCOs (and all currently in mass production) are *n*-type semiconductors. However, *p*-type TCOs are also necessary for the manufacture of transparent devices. One known *p*-type TCO is $CuAlO_2$. The intent of the project is to develop a method of preparing phase pure $CuAlO_2$ thin films and improve their electrical and optical properties. A bilayer Cu-Al structure was deposited by DC-sputtering on a SiO_2 substrate and annealed at temperatures from 400-900°C for 4 to 12 hours. Through this method, a maximum of 10% $CuAlO_2$ purity was reached. Co-sputtering was also used to deposit Cu and Al simultaneously onto glass substrate in the presence of oxygen, with a substrate temperature of 100-300°C. While increased temperature was shown to greatly improve conductivity, it showed a decrease in transmitted light and purity of the films.

Curved Functionalized Microfluidic Channels for Study of Cell Dynamics

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There have been numerous studies in which physical environments are simulated by growing cells on different stiffness substrates to observe changes in migration speed, cell stiffness, etc. [1]. However, these flat, two-dimensional systems do not accurately simulate *in vivo* environments in which cells exist. For the majority of cardiovascular tissue, it is most appropriate to model a system using micron-scale tubules. The objective of this study is to make observations on how different curvatures and stiffness affect cell proliferation, growth, and orientation preferences in tube-like structures. Polyacrylimide/bisacrylimide gels with substrate stiffness simulating different tissue environments were fabricated with diameters of 736 μm, 384 μm, and 114 μm. GFP labeled fibroblasts and MDCK cells were used to track cell migration and proliferation. Two-dimensional gels with similar substrate stiffness were also observed as a control for the system. From our initial observations, the curvature of the environment prompts the cells to migrate primarily along the major horizontal axis of the tube. The environment also coaxes fibroblasts to initially aggregate, in comparison to the control where there is little to no aggregation.

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Trap Density Analysis of High Dielectric Oxides on III-V Semiconductor

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The prospect of III-V semiconductors offer a higher efficiency alternative to the commonly used silicon, which is currently facing size limitations. One of the major problems surrounding the III-V semiconductors is the high trap density between the oxides and semiconductor interfaces. In this project, metal-oxide-semicondictor capacitors (MOSCAPS) were fabricated using different annealing processes and time frames. Samples were individually annealed in forming gas, nitrogen gas and) oxygen gas, respectively. By recording capacitance-voltage (CV) and conductance-voltage (GV) data measurements on the samples using the Impedance Analyzer, interface trap density (D_{it}) information can be interpreted using the Conductance method and the Terman method. These electrical characteristics offer suggestions on manufacturing processes which can minimize the midgap (D_{it}). It was discovered that annealing the sample with oxygen gas, as well as metal deposition immediately following the annealing process, yields the lowest midgap (D_{it}) among the tested conditions.

Designing a Microfluidic Device to Measure the Deformability of Cancer Cells

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Metastases is defined as a "tumor growth or deposit that has spread via lymph or blood to a body area remote from the primary tumor in a cancer patient." To spread in this manner, cancer cells must deform and pass through dense tissues or blood vessels with restrictions as small as a few microns. Understanding how these metastatic cells deform may give researchers valuable information to diagnose or treat cancerous patients. The project goal is to create a polydimethylsiloxane (PDMS) microfluidic device that enables the perfusion of cancer cells through narrow constrictions while imaging the cells on a microscope. The well-defined constrictions force the cell to deform its usually stiff and large nucleus and permit their mechanical characterization. We expect metastatic cells to be more deformable and to transit through the constrictions faster than non-metastatic cells. The device design was generated using AutoCAD software and transferred to a wafer by photolithography with spin-coated SU-8 photoresist. The wafer was then used as a mold for the final PDMS channels. The cells enter the device through an inlet and are perfused through multiple 5×10 micron constrictions. The efficiency of the device is currently being evaluated using images acquired by high-speed video microscopy.

Mobility of the Two-Dimensional-Electron-Gas in Lattice-Matched InAlN/GaN Grown by Ammonia Molecular Beam Epitaxy

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Nitride-based High-Electron-Mobility-Transistors (HEMTs) have several advantages over other transistor technologies including, high-power, high-frequency performance, high-voltage operation, and low-noise. HEMT operation occurs from the modulation of a two-dimensional-electron-gas (2DEG). The 2DEG channel is created at the InAlN/GaN interface where the conduction band bends below the Fermi-level. In this channel, the material acts like metals, hence a high mobility. The Fermi level can be brought below the conduction band by applying a bias and the channel can be pinched off. The ability to modulate the 2DEG creates the transistor. In the $In_{0.18}Al_{0.82}N$ / GaN system studied, the objective of this experiment was to optimize the growth temperature interrupt depth (GTID) into the GaN layer and to optimize the InAlN layer thickness. Samples were grown using molecular beam epitaxy with ammonia as the nitrogen source, and a photolithography procedure was used to pattern samples for electrical measurements. X-ray diffraction was used to verify InAlN was lattice matched to the GaN substrate. Hall measurements from the first series indicate that a GTID of 2.5 nm is the optimal conditions, with a mobility of 488 cm^2/Vs and a carrier density of 1.13×10^{13} cm^{-2}. Results from the second series demonstrate an optimum InAlN layer thickness of 10 nm.

Electrical and Optical Studies of Metal:Semiconductor Nanocomposites for Nanophotonics

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There is a great deal of interest in exploring the tunable optical properties of III-V-based materials, for applications such as terahertz photomixers, avalanche photodiodes, and telecommunication lasers. Thin-films grown with molecular beam epitaxy (MBE) systems allow for precise, controlled growth of devices that can be used for band engineering of III-V semiconductors commonly found in optical applications, such as GaAs and InAs. This project has been twofold. (1) Investigate the optical tunability of rare-earth monopnictide nanoparticle superlattices by adjusting superlattice period and composition. We show that intermediate energy states created by MBE-grown nanoparticles enable sub-bandgap tunability of GaAs and InP systems. (2) Study the Burstein-Moss blueshift in heavily-doped InAs systems as a function of MBE growth conditions and dopant type. By adjusting InAs doping, we have achieved an effective bandgap range of 0.46 to 1.16 eV as compared to the intrinsic value of 0.35 eV. Observed effective bandgap changes are used to study non-parabolicity of the InAs electronic band structure. Techniques used to investigate these materials include optical reflection and transmission spectroscopy measurements for both the near- and mid-infrared regimes. In addition to these projects, data parsing software created with MATLAB was developed to improve research group functionality.

Mobile Targeted Objects Steered by Chemical Micropumps

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It has been shown that bimetallic nanorods move in hydrogen peroxide on the order of a body length per second through self-generated electric fields. Although these rods move without an external power source, the direction remains random. This research aims to steer these nanorods using chemical micropumps, such as calcium carbonate microparticles, which generate radial diffusioosmotic flows. The focus of this project is to (a) study the movement of gold platinum nanorods near an array of calcium carbonate microparticles, and (b) develop a method for making a tunable, ordered array of calcium carbonate particles. Here we have shown nanorods moving with directionality between two calcium carbonate particles in the presence of hydrogen peroxide. Directed motion was also observed for a system with three calcium carbonate particles without the presence of hydrogen peroxide; this system may allow other charged objects to be steered. An ordered array was made by growing calcium carbonate in microwells on a PDMS surface. The wells were made using standard photo and soft lithography techniques. Currently, the method of growing calcium carbonate in the wells is being refined and we hope to eventually use this method to study the movement of nanorods in strategically patterned arrays.

Fabricating Nanostructures to Modulate Local Potential in Graphene

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Graphene is an atomically thin material with unique electrical properties. Its high carrier mobility at room temperature and good thermal conductivity make it a promising material for nanoscale circuit applications. One can also easily modulate the local potential of graphene with lithographic gates. Our efforts were directed at fabricating graphene nanoribbon (GNR) arrays and gold split-gates with length scales less than 100 nm. After performing electron beam lithography at different doses, using both PMMA 950 and ZEP 520 as resist, we developed our patterns at low temperatures using an ice bath. Oxygen reactive ion etching (RIE) was employed to etch the graphene into nanoribbon arrays, and electron gun evaporation was used to deposit the gold split-gates. We successfully fabricated nanoribbon arrays with a period of 100-180 nm using PMMA and arrays with a period of 60-80 nm using ZEP. We successfully fabricated split-gates with widths of 50-90 nm using PMMA/MMA bilayer resist. Graphene nanoribbon arrays and gold split-gates can be consistently fabricated using our methods. With these techniques, one can locally modulate the potential in graphene and study the transport properties of graphene *p-n* junctions. These techniques also lead to a method to build GNR-based radio frequency (RF) amplifiers.

Electro-Mechanical Characterization of Stretchable and Flexible Nanowires

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The fabrication of stretchable interconnects is imperative for producing stretchable and flexible microelectronic devices but current patterning approaches are limited to micron-scale features. Successful fabrication of smaller stretchable devices requires the use of new patterning methods and block copolymer lithography is an emerging technique capable of patterning feature sizes below 10 nm. Upon self-assembly, lamellar-forming block copolymers generate a pattern colloquially known as the "fingerprint" morphology, due to the loops, whorls, and curved interfaces. The lamellar pattern shares many structural features with stretchable interconnects for macroelectronics, and successful translation of the pattern into functional materials may enable the production of stretchable electronic devices at sizes magnitudes smaller than state-of-the-art. In this work, lamellar-forming polystyrene-*block*-poly(methyl methacrylate) (PS-*b*-PMMA) is used as a template to fabricate continuous gold nanowire networks (nanomeshes). The sheet resistance of these nanomeshes is below 1000 Ω/☐ and the nanomeshes are nearly transparent, with transmittances greater than 85% across the visible spectrum. Successful transfer of the nanomeshes to stretchable substrates shows that nanomesh continuity is maintained during strain because the pathlength between network nodes is much greater than the distance between nodes, allowing individual nanowires elongate and straighten in the direction of strain while maintaining continuous pathways for charge transport.

Growth of MoS_2 Atomic Layers

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The deposition of atomic layers of molybdenum disulfide (MoS_2) using a single-source precursor has been investigated. The single-source precursor tetrakis (diethylaminodithiocarbomato) molybdate(IV) ($Mo(Et_2NCS_2)_4$) was synthesized via two routes: a) Molybdenum hexacarbonyl $Mo(CO)_6$ was reacted with tetraethylthiuram disulfide ($Et_2NC(S)SSC(S)NEt_2$), and b) Potassium diethylaminodithiocarbamate ($KS_2CN(C_2H_5)_2$) was reacted with $Mo(CO)_6$. The precursor was purified by annealing at 150ºC in a tube furnace and utilized in the metal-organic chemical vapor deposition (MOCVD) growth of MoS_2 on SiO_2. The resulting atomic layers of MoS_2 were analyzed via scanning electron microscopy (SEM) and accompanying energy-dispersive x-ray spectroscopy (EDS). Electronic characteristics of MoS_2 layers were considered as well by finding current-voltage characteristics (IV curves) of molybdenum disulfide layers on the insulating silicon dioxide substrates.

Growth and Characterization of Synthetic Diamond

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Diamond exhibits many superior material properties such as high breakdown field, high saturation velocity, high carrier mobilities, optical transparency over a wide transmission range, and the highest thermal conductivity of all materials. These excellent properties make it desirable to deliver future high quality electronic devices and detectors. Hot filament chemical vapor deposition (HFCVD) was used to grow polycrystalline diamond on various substrates. AFM and SEM images confirmed diamond growth due to the resulting diamond facets on the substrate surfaces. A Raman shift value of 1332 cm^{-1} confirmed the presence of high quality nanocrystalline diamond. The full-width at half-maximum of the Raman peak was 15 cm. Ti/Au ohmic contacts were fabricated and annealed at 950°C for ten minutes in an H_2/Ar ambient environment. Linear-IV curves confirmed ohmic behavior. Ni and Al were used as Schottky contacts. Electrical properties of selected diamond films were also analyzed using the Hall Effect. Diamond grown on 3C-SiC yielded a mobility of 305 cm^2/v-s and carrier concentration of 2.3E19 cm^{-3}.

High Strain Low Voltage Induced Densified Vertically Aligned Carbon Nanotube Ionic Actuators

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Actuating materials that can provide high strain under low voltages are crucial components in artificial muscles, robotics applications, and micro- and nano-electromechaical (MEMs and NEMs) devices. The project proposes a modification to current carbon nanotube (CNT) based ionic actuation materials that would increase the actuation strain from a current 1-2% to 40-50% under low voltages (<4 volts). Using a biaxial mechanical densification process to increase the volume fraction (V_f) of vertically aligned carbon nanotubes (VA-CNT) from 1% to 40% while maintaining the vertically aligned morphology of the CNTs provides non-tortuous pathways for ion transportation which is crucial to creating fast, efficient, and high straining actuation devices. 1% V_f CNT forests are densified to 40% V_f, infiltrated with 40%wt Nafion polymer and immersed in two separate ionic liquids, 1-ethyl-3-methylimidazolium trifluoromethanesulfonate ($[EMI^+][Tf^-]$) and 1-butyl-3-methylimidazolium tetrafluoroborate ($[BMI^+][BF4^-]$) for strain testing. Experimentation revealed $[BMI^+][BF4^-]$ showing largest strains of 13% under 0-3v triangular wave signals while using $[EMI^+][Tf^-]$ showed ~5% strains under the same conditions. These results indicate that the size difference between the cations and anions in the ionic liquid are one critical factor that drives the actuation of the device.

Direct Nano Patterning of Anisotropic Conjugated Polymer

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Conjugated polymers are active materials for various optoelectronic applications. Their optical and electronic properties are highly anisotropic owing to the one-dimensional p-orbital overlap along the conjugated polymer backbone. In consequence, unless conjugated polymers are molecularly and macroscopically assembled and aligned with a well-defined structure, their interesting properties cannot be fully realized in their device applications. Our general strategy to achieve this was to directly pattern conjugated chains via Dip Pen Nanolithography (DPN) using a NanoInk DPN 5000. As the first step, we used poly(3-hexylthiophene) (P3HT) as a polymeric material and patterned dots and lines using a single cantilever tip and loaded the tip by directly pipetting the solution atop it. We evaluated the consistency of the dot sizes, line widths and any undesirable streaking by quantitatively analyzing the generated patterns with fluorescence microscope and atomic force microscope (AFM). Our results indicate that solution concentration, tip loading, bleeding, and preparation of the substrate are critical for reproducibly patterning conjugated polymer on Au and SiO_2 surfaces. This DPN technique will be applied to a novel stimuli-responsive organic semiconducting small molecules to build optical storage devices.

Identifying the Biomechanical Effects of UV Resistant Molecules and Nanoparticles on Human Skin

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The stratum corneum (SC) is the outermost layer of the epidermis and experiences significant amounts of mechanical stress. A lipid matrix surrounding layers of protein-filled cells forms the stratified SC, which is essential for proper functioning at the nano and micron-scale. Ultraviolet (UV) radiation due to sun exposure can alter the organization and structural integrity of the SC components. The administration of UV-absorbing chemical compounds and nanoparticles, namely TiO_2 and ZnO, can reduce damage. However, it is not fully understood how these UV-resistant treatments interact with the SC, and their efficacy at protecting biomechanical properties from UV exposure is unclear. In this work, we investigated the ability of various topical sunscreens containing UV-resistant molecules and nanoparticles to protect the biomechanical properties of UV-irradiated human SC. We examined the tissue's resistance to crack propagation, given by the intercellular delamination energy, as well as the driving force for damage, which is created by SC drying stresses. We also used attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR) to study UV inhibitor diffusion into the SC as well as structural changes that occurred from UV exposure. We found that the UV-resistant treatments successfully protected the biomechanical properties up to relatively large UV dosages.

Effects of Hydrophilic Membrane Modifications and Natural Organic Matter Fouling on Reverse Osmosis Membrane Performance

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Reverse osmosis diffusion processes offer an effective method for filtering brackish and sea waters. Thin-film composite (TFC) membranes function as the filter in these systems. However, the main drawback to using the TFC membranes is their susceptibility to fouling by natural organic matter (NOM) and various inorganic salts commonly found in brackish waters. One proposed method of mitigating this problem is to modify the polyamide active layer of the TFC membrane to be more hydrophilic. Polyethylene glycol (PEG) was determined a suitable candidate for this process. The focus of the project is to determine the effect of hydrophilic PEG grafting on membrane performance in the presence of NOM and model brackish water constituents. A previously developed technique for grafting the PEG was implemented. Using a tabletop reverse osmosis setup, feed stream conditions containing NOM and/or aqueous salts were tested for both grafted and unmodified membranes. Analysis of the permeate stream indicated that PEG-grafted membranes reduced permeate flux but also increased the ion rejection in most systems. Implementing PEG grafting in TFC membranes could potentially reduce the degree of fouling and ultimately lead to lower system costs.

WSi_2 Films for Superconducting Resonators

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Microwave kinetic inductance detectors (MIKDs) are promising for astronomy. In its simplest form a MKID consists of a thin film superconductor patterned into a resonator. We have started to examine tungsten silicide (WSi_2) as possible candidate for these detectors. WSi_2 for MKIDs has to have a suitable critical temperature (Tc) that is uniform over the wafer and very low (about 1K) and low stress. The Tc of sputtered thin film WSi_2 can be controlled by deposition conditions. We explored the parameter space of the WSi_2 sputter deposition by changing sputter power, Ar pressure and flow and coat time to find the ideal condition. We used sputter system located in the cleanroom in order to deposit WSi_2 on Si wafers in ultra high vacuum. We deposited WSi_2 at base pressures below 1.0×10^{-8} Torr on rotating Si wafer (30 rpm) by creating on Ar plasma above the WSi_2 target. We measured the thickness (using a SEM) and the Tc and the room temperature resistivity and the stress of our deposited WSi_2 films. We found that the WSi_2 we deposited is homogeneous over a 3-inch wafer on sample because Tc and film thickness do not change depending on the position on the wafer. Dependent on sputter conditions, we got Tc between 1.35K and 4.6K and room temperature resistance values between173 $\mu\Omega\cdot$cm and 8271 $\mu\Omega\cdot$cm. We also found that a change of the thickness of WSi_2 does not influence the Tc.

Carbon Coated Tin-Seeded Silicon Nanowires for Lithium-Ion Battery Anodes

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Carbon coated tin-seeded silicon nanowires (SiNWs) were synthesized by supercritical-fluid-liquid-solid (SFLS) method and explored as lithium-ion battery anodes. SiNWs are a promising anode material because of their high lithium-ion insertion capacity compared to carbon (3579 mA h g^{-1} vs. 372 mA h g^{-1}) and better tolerance than bulk Si of the large volume changes (280%) during lithiation and delithiation. However, Si is a semiconductor and requires conductive carbon additive to improve anode conductivity. Additionally, gold, the typical seed metal to grow SiNWs, creates deep electron traps in Si as well as catalyzes electrolyte decomposition resulting in continuous growth of a solid electrolyte interphase layer, which reduces anode stability. Tin seeding and coating with a graphitic carbon shell are promising ways to overcome these difficulties. Here we used monophenylsilane and bis(bis(trimethylsilyl)amino)tin to grow SiNWs containing a crystalline core and polyphenylsilane shell via the SFLS mechanism. The shell was then pyrolyzed to create a uniform graphitic carbon coating. The pyrolyzed SiNWs showed high capacities over 2,500 mA h g^{-1} at a slow cycle rate of C/10 without conductive carbon additive. Even at a relatively high cycle rate of 1C, the capacities of the SiNWs were higher than 1,000 mA h g^{-1} and stable for more than 100 cycles.

Stabilizing Fiber Optic Pressure Sensor Measurements by Fabricating an Enclosed Photonic Crystal Cavity

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Fiber optic pressure sensors are optical microelectromechanical systems (MEMS) devices used in a variety of industrial applications. Current sensors are assembled by affixing a silicon photonic crystal (PC) chip near an optical fiber-tip with a glass ferrule, which forms a Fabry-Perot (FP) cavity. However, environmental factors beyond human control decrease the sensor's overall measurement stability by inducing fluctuations in the cavity length. A potential method to reduce this variability is to incorporate the FP cavity construction into the fabrication stage of the PC itself. To accomplish this, a silicon wafer was patterned and etched downward to form PCs, which were etched radially outward to create overlapping spherical cavities. Silicon dioxide was deposited by low pressure chemical vapor deposition (LPCVD) to seal off the air cavities, after which their reflectivity was measured. Many PCs were fabricated with different hole diameters and PC heights to determine the optimal parameters that will yield the highest PC reflectivity. Based on our measurements, PCs with larger holes and smaller heights are optimal. By successfully implementing this design into the fabrication process, this compact pressure sensor's measurement reproducibility will significantly improve for its industrial applications.

Gender and Nanoscientists: The Public Communication of Nanotechnology

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The public communication of science and technology (PCST)—i.e., communication between scientists, the media, and society—is critical to enhancing discourse about emerging technologies. The changing media landscape calls for a reexamination of PCST; nanotechnology is particularly relevant because it is an emerging technology. Although imperative, scant research has examined the role gender plays in nanoscientists' PCST engagement. Using a multi-wave mixed-mode survey, this study examines how nanoscientists use new media to engage in PCST. Specifically, the Theory of Planned Behavior is used to understand how subjective norms operate in predicting PCST engagement across gender. Penultimate study results show that female nanoscientists use new media platforms (e.g., blogs, online forums, social networks, etc.) to communicate about science more often than male nanoscientists. Female nanoscientists also are more likely to target non-scientists with their communication efforts, while male nanoscientists are more likely to communicate with media professionals. Female nanoscientists also place greater importance on criticism to their PCST efforts from peers, department heads, and the public than their male counterparts. Although further research is needed to explore how gender moderates PCST, my initial findings in this study suggest that PCST perceptions and behaviors vary between male and female nanoscientists.

Electrokinetic Characterization of Nanoscale Metal Oxide Films

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At many solid-liquid interfaces, a potential difference develops due to chemical reactions at the surface. In this work, we measure electrokinetic properties of oxide surfaces using (1) laser-light scattering with a Malvern Zetasizer Nano, and (2) electroosmotic particle velocimetry measurements in a custom-built device. We deposit oxide films of controlled thickness and stoichiometry onto glass substrates, which we then analyze using electroosmotic flow tracing in electrolyte solutions of different salt concentration and pH. Using these data, we extract an electrokinetic zeta potential and compare our results with known literature values (as available).

Surface Scatterers on Slab-Wave Guides for Uniform Bacteria Growth

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Algal cultures grown in bioreactors are a promising source of renewable energy. However, algae growth is highly dependent on light intensity and standard bioreactors do a poor job at distributing light uniformly for algae utilization due to shading. Stacked bioreactors are built using sheets of glass where the light is directed into the sides of the glass. The light is totally-internally reflected in the slab-waveguides. Using photolithography, SU-8 photoresist, with a higher index than glass, was patterned to scatter the light. Experiments using florescent dyes, simulating a thin biofilm, were conducted to determine the rate at which the light intensity decreases at maximum SU-8 patterning density. The decrease was fit to an exponential and used to generate a gradient of coverage along the length of the reactor required for uniform scattering light distribution. The final gradient was generated by taking the required percentage at 40 different points along the reactor and tested for uniformity. Finally, single-stack reactors for algal growth were assembled to test the efficacy of different scattering schemes.

Spin Manipulation of Antiferromagnetic Devices

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We present progress towards strain control of tunneling anisotropic magnetoresistance (TAMR) in an antiferromagnetic (AF) based tunnel junction. Our devices are based on an exchange coupled NiFe/IrMn system interfaced with an MgO tunnel barrier. The antiferromagnet, IrMn, plays the active role in the device as the single magnetic electrode interfaced with the tunnel barrier. As antiferromagnets have a net zero magnetic moment, they cannot be directly manipulated by a magnetic field. Thus, we must employ other methods to manipulate the AF magnetic moments. Previous works on TAMR have manipulated AF moments indirectly by way of the exchange spring effect, where a magnetic field is used to manipulate a ferromagnet exchange coupled to an AF. Our recent work focused on reproducing this method of AF manipulation. The rotation of the AF moments causes a change in the resistance across the tunnel junction; we studied this TAMR effect in our devices below the Néel temperature of the iridium manganese. The observed hysteresis curves, a measure resistance as a function of magnetic field, are indicative of the presence of TAMR in our devices. These initial data measurements are a basis for the introduction of physical strain as a means of manipulating the AF moments in future work.

Fabrication of Nano Ion Pumps for Retinal and Neural Prosthesis

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Age-related macular degeneration is the leading cause of permanent vision loss in the United States. It and similar conditions may be treated using retinal prostheses; however, the operation of retinal and neural prostheses is currently based on electrical stimulation, which may pose health risks. In order to overcome these risks, an approach based on ion stimulation may be used. To facilitate implementation of this new approach, fabrication techniques for a gated selective nano ion pump were investigated. In order to fire neurons when desired, it is necessary for the pump to be capable of both sequestering and releasing ions as directed; this is accomplished using a gating system in which ions are driven through a membrane with their movement controlled by an applied voltage across the device. Anodized aluminum oxide membranes were selected to be used in the pumps due to their biocompatibility, previously investigated preparation, and ability to be functionalized for ion selectivity. These membranes were successfully fabricated on silicon substrates using techniques including photolithography, anodization, atomic layer deposition, physical vapor deposition, and reactive ion etching. Subsequently, the membranes were functionalized using crown-ether compounds and their ion selectivity was characterized using cyclic voltammetery.

Electrospun Nanofibers for Regenerative Medicine

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The human body possesses very limited regenerative capabilities. For example, severe damage to the peripheral nervous system (PNS) is irreparable even with surgical intervention due to the limited availability of Schwann cells, a type of glial cell that supports the extension of axons and communication between synapses. Tissue engineering strategies seek to facilitate the repair of damaged nerves to their full function with the combination of cellular therapies and biocompatible scaffolds, constructs that provide an encouraging environment for the regeneration. Electrospun nanofiber scaffolds are particularly attractive for repairing nerves and other anisotropic tissues because the electrospinning technique readily allows for uniaxial alignment of nanofibers, which mimics the anisotropic anatomy. In this study, electrospun nanofibers were used as the substrate for investigating the differentiation process of the human mesenchymal stem cells (hMSCs) into Schwann cell lineage for nerve repair. hMSCs were chosen particularly due to their clinical relevancy. We investigated the effects of fiber diameter, fiber density, and cell seeding density on the differentiation process. hMSC-derived Schwann cells were visualized through immunofluorescence microscopy for S100, a widely recognized Schwann cell marker.

Influence of Al_2O_3 Coating on the Annealing Behavior of Si Nanowires

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Doped semiconductor nanowires have been utilized in many prototype energy harvesting, molecular detection, and plasmonic devices. The use of these materials, which are synthesized via the vapor-liquid-solid (VLS) technique, is dependent on the robust control of carrier concentration. To enable the electrical activation of previously incorporated dopant atoms, rapid thermal annealing (RTP) is generally required. However, due to rapid surface diffusion, silicon nanowires deform at temperatures (~1000°C) far lower than that expected from their bulk melting point (~1400°C). To this end, we investigated conformal Al_2O_3 coatings as a route to suppress Si atom surface diffusion and preserve nanowire structure. We studied how nanowire morphology was impacted under annealing in a nitrogen ambient for no more than one second at 900°C, 1000°C, and 1100°C, and used scanning electron microscopy (SEM) to analyze our data. We observed that none of the coated and non-coated nanowires melted, even at the highest temperature, which contradicts previous data collected under vacuum conditions in our laboratory. We suspect the observed differences are due to the ambient chemistry and plan to test different gases, including Ar and H_2, in the future. Longer annealing times will also be explored in attempt to fully map the process window.

Electrohydrodynamic Jet Printing on Hydrogel Substrates for Cell Culturing Applications

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The ability to pattern cell cultures on a biologically compatible surface has the potential to provide a significant extension of cell biology knowledge. Electrohydrodynamic jet printing (E-Jet) has the capability to pattern said surfaces with various biological compounds. The focus of this project is to implement to the use of an e-jet printer to pattern a protein complex, called fibronectin, used for cell attachment, on the surface of polyacrylamide hydrogels. Fibronectin ink drops were printed that are smaller than the size of an individual cell (20-30 μm) and has the potential to be as small as 2 μm. Polyacrylamide gel stiffness can also be altered to mimic the softest of biological tissues. This research has the potential to not only advance cellular biology knowledge but also develop a way of constructing three-dimensional cellular patterns or bio-arrays, as well as advance the research of tissue engineering.

Electron Blocking Layer in Gallium Nitride Devices

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The electron blocking layer (EBL) is thought to increase efficiency in gallium nitrite (GaN) light emitting diodes (LEDs) and laser diodes. In the LED electrons pass through active region, the region where electrons transition to a lower energy level and emit a photon. An EBL will rebound electrons that escape the quantum well back into the active region and produce light. For our project we looked at how two different substrate growth planes, m-plane and c-plane, affect the potency of the EBL. The LED m-plane and c-plane samples were grown using metal organic chemical vapor deposition (MOCVD) on sapphire substrate and bulk GaN substrates, respectively. After processing the samples, we looked at external quantum efficiency (EQE), or percentage of electrons that produce photons, and its dependence on temperature and current. For the c-plane LEDs without an EBL there is a decrease in EQE by up to 15% as compared to the samples with an EBL. The m-plane samples, however, show that there is no significant difference between samples with and without and EBL for the current densities considered in this study. This shows that growth plane has a significant effect on the necessity of the EBL.

Deposition and Characterization of Magnetic Permalloy for Future Endomicroscope Actuators

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Permalloy is a material that expresses magnetic properties when nickel and iron are combined in an 80% to 20% ratio, respectively. A permalloy film is created by electroplating a wafer in a nickel-iron solution. The biomedical community has taken recent interest in the development of permalloy structures. One potential application in that field is as an alternative to comparatively large piezoelectric actuators currently used in novel prototype endomicroscopes. The use of permalloy will be attempted in order to produce smaller actuators that will instead apply a magnetic field to control lens movement. This project aims to characterize the different permalloy films that are plated when variables such as current density, plating duration, and pulse timing are varied in the electroplating process. Oxide-coated wafers were deposited with a chrome-gold seed layer and a secondary oxide coating on the back provided insulation. Photoresist was developed on wafers after electroplating, and was removed in order to begin etching. Ferric chloride, gold etch, and CR-14 etchants were used to etch to the oxide; plasma etch machines etched the oxide and the silicon in order to create cantilevers. A magnetic field was applied to test the magnetic properties of these permalloy cantilevers.

Designing Directional Micro-Machined Microphones

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The newest smart phone designs, using noise rejection algorithms, rely strongly on high signal-to-noise ratio (SNR) audio capture. Techniques currently used, involve measuring the difference signal between two "standard" omnidirectional microphones physically separated in space. However, the ability to resolve small difference signals is limited by poor matching or high noise microphones. We designed the pivoting micro-machined microphones that measures spatial pressure differences directly, therefore two microphones are no longer required, reducing cost, power consumption, size, and eliminating microphone matching issues. We found that the rocking structure of the device, anchored by pivots, naturally senses pressure gradients, making it potentially more sensitive than the standard two-omnidirectional-microphone techniques being used. When designing and simulating devices using AutoCAD and ANSYS, we obtained a figure of merit of the first modal resonance showing optimization near the center of the audio band, between (1-3 kHz) to ensure the highest sensitivity and good directivity over the desired range of operation. We discovered that designs that are more flexible will move more in response to an excitation force and have a higher voltage output per input acoustic pressure. During the designing process, we saw that devices with a thinner epitaxial layer and/or thinner and longer pivots produce better figures of merit allowing for lower minimal detectable signal (MDS).

Studying the Interfacial Dynamics of Miscible Fluids with Microfluidics

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Many industrial and biological systems are governed by a convection-diffusion process across an interface between two miscible fluids. Enhanced oil recovery, cleaning products, and mucus in our lungs are all examples. One key attribute of these interfaces is a transient interfacial tension. In this project, we are interested in how the interface evolves over time, which is vital to understanding the transient nature of the interfacial tension. We chose microfluidics as the experimental platform to explore the mass transfer. The small volumes used in microluidics minimize gravitational effects and reduce safety issues associated with some fluid systems. We also take advantage of the temperature dependence of solubility, namely the upper critical solubility temperature (UCST) of a given fluid system. The framework of the experiment is to create droplets below the UCST, trap a droplet at the stagnation point, and then heat the droplet above the UCST to track the interface. Over the summer we investigated a variety of options for each of the experimental steps, and how they can be combined to make an integrated microfluidic device for the study of interfacial dynamics. Design features considered include droplet formation devices, fluidic traps, microheaters, and various control strategies.

Micro-Scale Microbial Fuel Cell: Petroleum Biosensing

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Clean water resources are a necessity to life. In this research, we analyzed the cleanliness of water in real time by using a small sensor: a micro-scale microbial fuel cell (MFC). The micro-scale MFC contains a specific strain of bacteria that produces electrons by consuming organic substrates and transfers the electrons to the electrode via their catabolic reactions. The micro-scale MFC was evaluated as a function of substrate concentrations as well as petroleum concentrations, one of the critical pollutants of water. Substrate concentrations showed a consistent efficiency throughout the process. The changes in current from the MFCs indicate how catabolic reactions of bacteria are influenced by those external stimuli. According to the measurements, the micro-scale MFCs show promise in safe, environmentally-friendly, and inexpensive portable sensors to monitor the quality of water.

Infrared Photodetectors With 2D Materials

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As computer processor speed rises exponentially, the bandwidth required for inter-processor communication grows as well. Integrated optoelectronics may solve the interconnect bandwidth bottleneck. The unique properties of 2-D materials could help realize the next generation of high-speed optical communications. The three necessary components are infrared transmitters, modulators and detectors. In this work a new heterostructure photodetector has been designed and built using monolayer graphene and varying thicknesses of molybdenum disulfide. This device provides sensitivity in the infrared region optimal for optical communication (1550 nm) while maintaining low dark current. Monolayer graphene grown by chemical vapor deposition (CVD) has been patterned onto mechanically exfoliated molybdenum disulfide (MoS_2) and titanium-gold contacts made to both materials. Initial electrical characterization of the devices has been performed. The resulting resistance and linearity of the contacts agree with predictions. These preliminary results are encouraging and indicate the photodetector device will perform as expected.

Dynamics of Bacterial Quorum Sensing in Microfluidic Devices

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In this study, we examined and modeled the dynamics of the *luxI*/*luxR* quorum sensing mechanism engineered into a population of *E. coli* grown in a microfluidic device. Understanding this molecular communication mechanism at the population level is crucial for the potential use of bacteria as biosensors among other biomedical applications. The use of microfluidics is advantageous towards this goal, as it gives us control over many elements such as population density and dynamic media variation. We have fabricated and tested SU-8 molds and the PDMS devices, run fluorescent experiments measuring the bacteria's fluorescence, and finally fit a mathematical model consisting of mass balances of relevant chemical species to the experimental data. The resulting model allows for the prediction of bacteria population responses to a variety of different inducer concentrations and profiles, as well as for scenarios outside of the microfluidic devices. This complete experience demonstrates an increased understanding of not only the signal mechanism, but the entire design, experimentation, and validation of a complex study of molecular communication between bacterial cells.

Graphene-Based Electro-Optic Modulators

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In recent years, graphene has received a lot of attention because of its unique features, such as its high mechanical strength, unique optical properties and the ultrahigh electron mobility. These unique optical properties promise a wealth of novel applications and devices. For example, graphene based ultrathin and ultra-broadband electro-optic modulators, which employ the electrostatic-doping-induced transparency of graphene to create a voltage-controlled optical absorption, have enabled a variety of new applications in physics. However, we must take the evil with the good, as fabricating devices that rely on a single molecular organic layer can be very challenging. One of the main challenges is to fabricate ohmic metal contact on graphene, as the density of states near Dirac point is low. High contact resistance in such thin devices can severely degrade the performance. In this study, we focus on the influences of wetting metal layers and doping of graphene on contact resistance. We prepared thin film structures consisting of Al/Cr, Ni, Ti top-electrodes on transferred graphene grown by chemical vapor deposition. The graphene was placed on an aluminum oxide layer and gated from a doped Si wafer. The contact resistance was measured as a function of gate voltage, i.e. doping concentration.

Graphene-Based Electro-Optic Modulator Fabrication

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Graphene exhibits many useful properties including a high carrier mobility, fast relaxation of photo-excited carriers, and carrier-density-dependent optical absorption. By gating graphene, the type and density of carriers can be tuned over a large energy range, and therefore, optically broadband, high-speed electro-optic modulation is possible. Graphene modulators fabricated based on this principle have been utilized as a fast actuator to stabilize unwanted noise in lasers, paving the way to a new generation of ultra-low-noise optical frequency synthesizers. Although graphene modulators provide the above-mentioned benefits, during their fabrication it remains challenging to prevent defects introduced by chemicals, such as photoresists and developers, or processes such as sputtering and UV light exposure. The focus of this project is to compare the performance of graphene devices of which the top metal electrodes are fabricated by wet-etching to those fabricated by a lift-off procedure. Different approaches of wet etching are also investigated, which include the use of different metal etchants and photoresists. The study of the graphene-compatible fabrication methods in this project will not only improve the current performance of modulators but also contribute to the field of graphene electronics.

Nanostructuring Diamond for Quantum Sensing

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The ability to structure diamond on the nanoscale is crucial for realizing diamond's potential as nano electro-mechanical material. In particular, diamond plays host to the nitrogen-vacancy center, an atom-like defect that is promising for quantum sensing applications. Processing of diamond, however, is difficult and not well established. In this work, we have pursued two techniques to achieve efficient and controlled diamond structuring. Firstly, we used chemical mechanical polishing (CMP) to planarize and smooth diamond samples. Using 6 μm diameter diamond powder in an ethane-diol suspension, polishing rates were < 10 μm/hr. Scratching of the diamond surface by the nanodiamond powder was observed. Secondly, we explored an $Ar/CF_4/O_2$ inductively coupled plasma (ICP) etch and found the diamond etch rate to be 16.7 μm/hr. The surface quality depends heavily on the smoothness of the starting surface, with any irregularities in the starting surface becoming more pronounced after etching. Achieving a fast and smooth diamond thinning process will enable the production of high-quality diamond nanostructures for enhanced sensing.

The Study of Disposable Substrates in Surface Acoustic Wave (SAW) Devices

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SAW devices have been widely used in microfluidics to manipulate fluids and particles. Successful applications include single cell manipulation, particle focusing, cell separation and cell sorting. However in typical SAW devices, if channels are defective or if channels become contaminated after use, the SAW device cannot be reused because the channel component is directly bonded to the SAW device substrate. Here we show that SAW devices, whose components are coupled through a flexible medium, can perform the same functions as that of a typical SAW device. Polymer channels, which are normally directly bonded to a piezoelectric substrate with interdigital transducers, are instead bonded to glass slips and coupled to the piezoelectric substrate. The modified SAW device, coupled with 25 μm double-sided tape and petroleum jelly, retains the ability to manipulate particles with an increase of power. This study shows that coupled SAW devices can be as effective as typical devices, making them more economic.

Improvement of Tin Sulfide Solar Cell Efficiency

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Currently, many of the elements used in commercial solar cell technologies are toxic or scarce. A possible alternative to these technologies is the use of tin sulfide-based solar cells. However, the record efficiency of this type of cell is 2.46%, significantly less than other technologies [1]. Solar cells function by using absorbed light to separate charge carriers and create a usable current. This solar cell uses the SnS layer as the p-type material of the heterojunction and zinc oxysulfide as the complementary n-type material. Optimizing the conduction-band offset of two layers can increase efficiency [2]. The focus of this project is to find additional increases in efficiency through surface treatment of the silicon oxide substrate to increase the cell's absorbance [3] or by minimizing the resistance contribution of the back contact through the use of other metals.

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The Impact of MEMS-Produced Micro-Electrode Material Coating on Dental Plaque Biofilm Growth

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The development of dental biofilms can create acidic environments due to the production of metabolic byproducts. A micro pH electrode has been created using microelectrical mechanical fabrication techniques to continuously measure the pH at different distances from saliva-coated surfaces on which biofilms can develop. A coating was needed for this micro pH electrode to prevent the environment of the biofilm and oral cavity from altering the functionality of the pH sensor. Three different material coatings were selected for their known biocompatibility with living cells: parylene, silicon dioxide, and silicon nitride. To determine which coating was best suited for this purpose, the micro electrode was tested in micro flow cells inoculated with fluorescent dental bacteria. The cells and pH electrode were then imaged in three dimensions using a computer controlled confocal laser scanning microscope.

Radio Frequency Switches Using Phase Change Material

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Phase change (PC) materials have two separate states: crystalline and amorphous. In the crystalline state, the electrical resistance is relatively low while high resistance level is observed in the amorphous state. If the two states are properly controlled and resistance level difference is sufficient throughout radio frequency range, this material can be utilized as an ohmic switch. The main goal of this project is to fabricate RF switches using GeTe, a PC material. More practical structure is proposed with separate RF and heater electrodes. For better performance and effective phase transition, fabrication process is characterized. First, to improve metal contact resistance, oxidized Moly electrodes in contact area with GeTe has been etched using diluted HF solution. Also, additional AlN layer is deposited under the GeTe switch for better heat dissipation into the high resistivity Si substrate. Additional oxide layer is also deposited on the bottom heater electrode to get better access to the GeTe area for phase transition and improve crystallization condition. The measurement resuls of the fabricated GeTe switch will be also provided.

Fabrication and Characterization of InGaAs Metal-Oxide-Semiconductor Capacitors (MOSCaps) with HfO_2 Dielectrics

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III-V InGaAs metal-oxide-semiconductor field effect transistors (MOSFETs) are promising candidates for next generation low power logic technology. A major challenge for III-V MOSFETs is the development of a suitable gate dielectric with low interface trap density. This project focused on the fabrication of InGaAs MOSCaps with HfO_2 dielectrics grown by atomic layer deposition (ALD). Several studies were conducted involving *in situ* ALD surface cleaning, HfO_2 growth temperature and post-deposition forming gas anneal (FGA) parameters. The two types of surface cleaning investigated to reduce interface trap density were hydrogen plasma/TMA and nitrogen plasma/TMA. Various HfO_2 deposition temperatures were explored to probe the ALD window of HfO_2 growth. Finally, the post-deposition FGA was optimized by testing different ramp rates and annealing temperatures. The InGaAs MOSCaps were characterized using capacitance-voltage (C-V) measurements, and the interface trap densities were evaluated using the conductance method.

Solid-State Pulse NMR of $(CdSe)_{13}(propylamine)_{13}$

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Cadmium selenide (CdSe) nanoparticles exhibit unique electrical properties due to quantum confinement of electrons, showing potential for wide-ranging nanomaterial applications. A constituent of these nanoparticles are so-called “magic number clusters” of CdSe, which are stable molecular units that can be synthesized with high purity. The focus of this project was to successfully acquire 113Cd NMR spectra of (CdSe)13, one of the magic number clusters, using several different pulse sequences and paramagnetic doping techniques. This was challenging given the low number of NMR-active spins in the sample along with exceptionally slow relaxation rates. However, 113Cd NMR results were obtained on undoped (CdSe)13 capped with propylamine ligands using Driven Equilibrium Fourier Transform (DEFT) and Cross-Polarization Magic Angle Spinning (CPMAS) techiniques. A quick background on NMR and results will be presented.

Full Body Silicon Medical Tweezers for Cancerous Tissue Detection and Characterization

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It had been shown that tissue elasticity and electrical permittivity have been promising non-optical markers for identifying cancerous tissue. Therefore the goal of the project was to create a device that would be able to detect these properties and further characterize cancerous tissue *in situ*. Because of the advantages of micro-fabrication technology, a full body silicon device can allow for optimal sensor integration. As a result, full body silicon medical tweezers were fabricated with multiple sensors, eight strain gauges, four sets of platinum wires and sixteen platinum electrodes. Strain gauges were used for tissue elasticity by monitoring the insertion force, and the platinum wires were designed for tissue permittivity measurements. Additionally, the platinum electrodes have the capability of electrical physiology signal measurements. The seven-mask device was designed using CAD software and a MATLAB program that can automatically generate Caltech Intermediate Format (CIF) files and can allow for dynamic changes to the structural parameters such as height, radius, and probe distance. Strain gauge resistivity, structural rigidity, and impedance measurements will be performed to verify the performance of the tweezers and feasibility for future medical applications.

Micro-Fabrication of Chemical Field-Effect Transistor

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A transistor amplifies electrical signals applied to the gate electrode. The metal-oxide field-effect transistor (MOSFET) is the most commonly manufactured example. If one replaces the metal gate of a MOSFET with a selectively permeable membrane, it enables transistors to amplify electrical signals based on the ion concentration of a solution. Such devices are known as chemical field-effect transistors (ChemFETs). Integrating micro-fabrication techniques such as photolithography and oxidation, with transistor knowledge, we can fabricate ChemFETs at the micro-scale. A research group at Minnesota envisions these micro-scale ChemFETs could analyze sweat droplets as small as one millimeter in diameter. This will allow noninvasive tests of neural function and detect diseases such as cystic fibrosis, osteoporosis, diabetes, and other conditions, as part of a larger program to use the mapping of sweat production to determine neural function. This would be used to detect neuropathy caused by diabetes, chemotherapy, industrial or defense-related exposure to toxins, alcoholism, HIV, and other conditions. Casting of poly(2-hydroxyethyl methacrylate) and including ionophores, valinocycin and ETH 2120, in the membrane enhance the selectivity and responses of ChemFETs.

Directed Self Assembly of Mixed Nanowire Populations via Lithographic Microwells

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Vertical nanowire arrays offer promising applications for energy harvesting and storage. The Keating group has developed a method by which vertical arrays were formed over areas as large as 10 cm^2 by harnessing the internal anisotropy of segmented nanowires. Array quality of was increased when these particles were assembled in microwells fabricated using photolithography. This summer microwells were used to assemble solid gold or palladium wires around 4-7 μm in length. Wires were synthesized using template electrodeposition and coated with a thin silica coating. These wires, which typically form horizontal arrays will form vertical arrays in appropriately sized microwells with standing percentages as high as 100% in certain wells. When the width of the well was longer than the wire length the wires formed a smectic pattern. When the length of the wire was longer than the width of the well, standing percentages as high as 80% were seen across the array. Taller wells increased standing percentage. Mixtures of gold and palladium were assembled and observed using a confocal microscope to distinguish the differing reflectivity of the wires at different wavelengths. Further work to be done includes testing the conditions which effect mixing and demixing.

Synthesis of Metal Supported Catalysts for the Hydrogenolysis of Lignin

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Plant biomass, a renewable resource rich in carbon and potential energy, is a promising feedstock to displace non-renewable petroleum, in part because it is low-cost and readily available. In particular, lignin is an under-utilized feedstock that is currently considered as waste. The structure of lignin makes it difficult to deconstruct and therefore utilize; however, its rich aromatic composition is an ideal precursor for a variety of fuels and value-added reactive intermediates. As a result, our research goal focuses on developing catalytic conversion technologies that produce a narrow distribution of phenolic-like products from lignin with minimal energy and material inputs. To accomplish this goal, we have synthesized various abundant transition-metal (copper, iron, nickel, and cobalt) containing metal-oxide (silica, alumina, and titania) catalysts by various methods to facilitate selective aryl ether hydrogenolysis. Specifically, we have generated over 24 different variations of catalysts, not only producing different combinations of transition-metal active components with metal-oxide supports but also generating mesoporous (pore sizes between 2-50 nm) variants. Considerable efforts were also devoted to developing/adapting synthetic procedures, determining optimal synthetic conditions, and developing a catalyst purification method that avoided char formation during catalyst drying and calcination.

Big Ideas on Small Matters: A Multi-Method Approach to Understanding Knowledge Transfer Practices in the NNIN

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While the National Nanotechnology Infrastructure Network (NNIN) attempts to foster knowledge-sharing among different sites, there has not yet been documented evidence of the specific knowledge transfers that occur within the network. Moreover, there has been a significant lack of research done in studying knowledge transfer practices outside of firms and private businesses. The current project entails observing laboratory areas where knowledge is transferred and surveying cleanroom users in order to understand the network's flow of knowledge. Once identifying the typical sources of the knowledge transfers and documenting the types of transfers that occur, the current hypothesis states that the surveys (n=57) will stay consistent with the findings of the laboratory ethnography. The results show that a significant amount of information originates from the staff members and equipment of the facility while there is minimal evidence supporting that there is a significant number of knowledge transfers among users. Furthermore, these transfers typically include codified knowledge rather than tacit knowledge or tacit-codified knowledge. The implications of this pilot work address the concerns of future interactions within the NNIN and within other scientific networks at large.

Exploring the Effects of Theophylline on Neutrophil Function in Inflammatory Diseases

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Neutrophils play a key role in the human immune system as the first cells to migrate to sites of inflammation. Several common respiratory diseases, such as chronic obstructive pulmonary disease (COPD) and asthma, are characterized by excessive chemotaxis and damaging apoptosis of neutrophils around infection. Theophylline, one potential therapeutic candidate, was employed to examine drug effects on neutrophil function. The chemotactic behaviors of neutrophils were monitored using a microfluidic platform after incubation with various concentrations of theophylline for different time periods. Theophylline works to limit the motility of neutrophils in small concentrations and long incubation times; however, there is no influence on the polarization of neutrophils. Meanwhile, theophylline induces a tremendous decrease in neutrophil viability based on colorimetric assay, and this viability is dependent on drug exposure time. This work provides new insights on how theophylline affects neutrophil function *in vitro*, potentially guiding drug application for the treatment of neutrophilic inflammation *in vivo*.

Azobenzene Modified DNA for Light-Induced DNA Stringency

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We used azobenzene-modified DNA and DNA-modified gold nanoparticles to study DNA hybridization stringency, or differentiating between perfectly matched DNA and partially matched DNA during DNA hybridization. Azobenzene is a photo-switchable molecule. The *trans* form of azobenzene can be converted into the *cis* form by using UV light. The reverse isomerization will occur under blue light. Azobenzene can be chemically attached to DNA where it will still photoisomerize, allowing us to use light to control whether the DNA is double stranded or single stranded. This light controlled DNA can then be implemented into DNA stringency techniques. This summer, we functionalized gold nanoparticles with DNA, prepared both target DNA and azobenzene modified DNA in buffer, and then attached that DNA to glass slides to use in chip-based assays. We then tested the DNA stringency conditions on glass under UV light using DNA modified gold nanoparticles as probes, and performed effective controls. This knowledge will help to create a procedure for an effective method for using visual sensing in collaboration with DNA stringency to differentiate between perfectly matched DNA and partially matched DNA.

Fabrication of Smart Gels with Tunable Stiffness

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The differentiation of stem cells is influenced by many factors, one of which is the stiffness of the cellular microenvironment: soft substrates lead to neuronal cells, intermediate stiffness substrates lead to myogenic cells, and very rigid scaffolds lead to osteogenic cells [1]. To further understand the kinetics of stem cell differentiation, we design degradable polyacrylamide hydrogels which allow us to change substrate stiffness during differentiation and observe the effect of this change on the lineage specification of stem cells. With this purpose in mind, 8% polyacrylamide gels composed of permanent *N*,*N′*-Methylenebisacrylamide (BIS) and degradable *N*,*N′*-Bis(acryloyl)cystamine (BAC) cross-linkers are constructed. The shear modulus of these gels can be changed from ~ 10 kPa to ~ 400 Pa. Under normal conditions, these gels would lead to osteogenic and neuronal differentiation respectively. This hydrogel is found to be degraded in a time span that maintains continuous cell proliferation with the biocompatible chemical Tris(2-carboxyethyl)phosphine hydrochloride (TCEP) in Dulbecco's Modified Eagle's Medium (DMEM). Since stem cells are known to commit to their final cell type within a week, using these gels will allow us to test whether the time point at which the scaffold is degraded effects the final lineage specification of the cells.

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Resistive Switching in TaO_x with Varying Oxygen Content

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Silicon based non-volatile memory is nearing its practical limit and several other possibilities are being examined more closely as potential replacements. One of these possible replacements is Resistive Switching. Resistive switching is a phenomenon in which a Metal-Insulator-Metal (MIM) structure can change to a Low Resistance State (LRS) at the application of a set voltage and then be switched back to a High Resistance State (HRS) by the application of a reset voltage [1]. Much about resistive switching is still unknown in regards to which materials switch and why. Our group examined how the various set and reset voltages of TaO_x changed when prepared with different oxygen to argon ratios during sputtering. By performing electrical characterization of the samples with a basic probe station we were able to determine the set and reset voltages of each sample, each with differing oxygen contents during formation. Ultimately it was found that the oxygen content during sample preparation changed the initial resistance as expected but did not change the set or reset voltages.

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Delivery of Immunosuppressive DNA Drug for Treatment of Autoimmune Diseases

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In autoimmune diseases, large DNA fragments such as the body's own "self" DNA can stimulate an immune response, attacking your own cells. Small DNA fragments, however, do not elicit such a response, so these small fragments can be administered to a patient to occupy the receptors, stopping cells from responding to self-DNA fragments. The focus of this project was drug delivery methods for these CpG DNA fragments. First, a cationic liposome was successfully used to transfect the DNA drugs into the mouse fibroblast cells, significantly reducing the immune response to large B-DNA molecules. The cationic liposomes have some limitations when utilized in other cell types, so other nanoparticle drug delivery methods were explored. First, a silica nanoparticle coated with positively charged Polyethyleneimine (PEI) was used to bind electrostatically to the DNA drugs, similar in method to the cationic liposome. This was ineffective at suppressing cytokine output, so silica nanoparticles with Streptavidin coated on its surface were bound to CpG tagged with Biotin. This complex also failed to suppress the immune response. We then used Silica/PEI nanoparticles bound with B-DNA, which elicited almost no immune response. This demonstrates that silica nanoparticles are an ineffective method of delivering the DNA drugs to cytosolic receptors.

Synthesis and Characterization of Functional Organic and Supramolecular Nanomaterials

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Artificial photosynthetic systems offer a potential renewable energy source to manage the increasing global energy demand. Organized dye molecules, in particular *J*-type aggregates, exhibit efficient excitation-energy transfer suitable for light-harvesting antennas necessary in artificial photosynthetic systems. We designed and synthesized a porphyrin chromophore (**1S**) so as to self-assemble into a supramolecular polymer with a stable *J*-aggregate mode in solution. UV-Vis, IR, NMR, and CD spectroscopic analyses were performed to investigate the aggregation properties.

Evaluation of Planar Organic Electrochemical Transistor Device Geometry for the Characterization of Barrier Tissue

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Composed of a metallic source, drain, and gate contacts and a conducting polymer channel, Organic Electrochemical Transistors (OECTs) conduct both ions and electrons allowing signal transduction with biological systems. The interfacing of electronics, such as OECTs, with biological systems, using novel organic materials has led to endless applications in the field of bioelectronics today. For our studies on the effects of electronic device geometry on the characterization of the barrier tissue system, a planar OECT is specifically chosen, because it simplifies the fabrication process, cells can be seeded directly on top of the transistor and the electrical characterization can be correlated with optical characterization. Gold is selected for the source, drain, and gate contacts because it is biocompatible, an excellent conductor and forms an ohmic contact with the p-type semiconductor polymer poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) (PEDOT:PSS) that is used for the channel and the gate active layers. These fabricated transistors are stable and biocompatible. Electrical characteristics of the transistor were influenced by the device geometry and after a barrier tissue composed of Madin-Darby canine kidney (MDCK) epithelial cells was grown on the transistor, the optimal device geometry for the characterization of barrier tissues was determined.

Advanced Synthesis and Nano-Characterization of Graphene on Pt(111) Substrates

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Graphene was grown by surface precipitation and chemical vapor deposition on platinum (111) substrates. Surface chemical composition and estimated film thickness were determined using Auger electron spectroscopy (AES). Platinum-graphene workfunction differences were measured with Kelvin probe force microscopy (KPFM) and shown to be correlated with fabrication methodology. Likewise, x-ray photoelectron spectroscopy (XPS) indicated that platinum-graphene charge transfer and interlayer interaction was affected by growth technique. Inverted surface topographies were observed by atomic force probe microscopy (AFM); the possibility of selective adsorption of water molecules on the substrate surface is proposed. Surface defect states were analyzed with scanning tunneling spectroscopy (STS). Supplemental topographical analysis was conducted using helium ion microscopy (HIM).

Current-Voltage Characteristics and Two-Step Photocurrent Generation in Lattice Matched Quantum Dot Solar Cells

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The Intermediate Band Solar Cell (IBSC) is now widely researched, promising to improve photovoltaic energy conversion for use as an alternative energy. According to the concept, such a solar cell can utilize photons with smaller energy than the band gap, which cannot be absorbed in current solar cells, resulting in an increase in photocurrent while maintaining a high open-circuit voltage. A promising method of realizing such an IBSC is employing quantum dots (QDs). Many active research efforts are underway using stacked QD layers in lattice-mismatched systems such as InAs/GaAs, but have fundamental issues due to the detrimental effects of accumulated strain. Here, we explore the fabrication and operation of a QD-IBSC in a lattice-matched system (GaAs/AlGaAs) grown by molecular beam epitaxy using the droplet epitaxy method, where such effects are eliminated. GaAs QD layers are embedded in the active layer of an AlGaAs solar cell. We characterize the QD-IBSC to demonstrate the viability of this system and suggest explanations for the current-voltage characteristics. Using multiple light sources for illumination and measuring photocurrent generation, we observe a two-step photocurrent generation (first transition to photogenerate carries within the QDs, and second to excite these carriers out of their confinement), the key operating principle of IBSCs.

Surface Ligand Density-Dependence of Cell Migration on Photoactivatable Substrates

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Cell migration is an important component of cancer metastasis and the wound healing process, where the collectivity of cellular migration can be influenced by many factors such as the composition of the extracellular matrix (ECM), soluble factor gradients, etc. In this study, the effect of surface density of an ECM ligand on collective migratory characteristics is explored using an easily tunable, photoactivatable substrate. Gold substrates were functionalized using cyclic Arginine-Glycine-Aspartic Acid (cRGD) ligand and a photocelavable Polyethylene Glycol (PCP) with different mixing ratios ranging from 1:100 to 1:10,000. Two cell lines, the HeLa cervical cancer line and the Madin Darby Canine Kidney (MDCK) line, were seeded on circular patterns ($r=75\mu m$) for five hours and then released to study migration speed on each surface prepared. Results show an increasing migration speed for MDCK cells as the cRGD ratio decreases ($p < 0.001$) and a static migration speed for HeLa cells on all substrates. Additionally, HeLa cells changed from collective to non-collective migratory behavior at a threshold cRGD density of 1:10,000. The platform created here shows promise as a high throughput test bed for the effect of surface ligand density on collective migration characteristics for use in future cancer studies.

Hydrogen as a Potential Cause of Native *n*-type Conductivity in Tin Dioxide

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Tin dioxide (SnO_2) has been widely used for chemical sensors and transparent conductive films because of its wide band gap energy of 3.6 eV and n-type conductivity. The native n-type conductivity of SnO_2 is often explained by assuming oxygen vacancies act as shallow donors. However, density functional theory calculations have disproved this assumption and instead point to hydrogen acting as "hidden" shallow donors in SnO_2 [1]. To overcome the difficulty of analyzing hydrogen-related phenomena, this analytical study on hydrogen behavior was performed using ^2H as an isotopic tracer. Pure and indium (In)-doped SnO_2 ceramics and natural SnO_2 single crystals were heated in humid O_2 gas enriched with ^2H_2O to introduce ^2H into the SnO_2 lattice. Characterization was performed with secondary ion mass spectroscopy and thermal desorption spectroscopy, as well as Raman, photoluminescence and Fourier transform infrared spectroscopies. Comparison of the pure and In-doped samples points to hydrogen sitting in different types of defects: interstitial in pure samples and substitutional in In-doped samples. Investigations using single crystal samples also revealed that ^2H could diffuse along the <001> axis but not along the <110> axis.

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XPS Analysis of Sulfide and AlN Based Buffer Layers for Epitaxial ZnO Growth

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Thin films of non-polar MnS and AlN/MnS were grown on Si (100) by pulsed laser deposition (PLD). The chemical compositions of the samples were investigated by angle-resolved X-Ray photoelectron spectroscopy (XPS). It was found that AlN serves as a barrier to preserve MnS films from oxidation. It was also found that Mn-Si bonds existed on the surface of silicon, while Si-S bonding was not observed. Finally, a native SiO_x layer was observed to diffuse to the surface of the sample, residing on top of epitaxial AlN. It is also likely that a thin Al_2O_3 layer existed alongside SiO_x.

Electron Transfer Dynamics in Polymer Solar Cells Studied by Femtosecond Transient Absorption Measurements

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Organic molecules offer a cheaper alternative to traditional bulk crystalline materials in solar cells. While organic solar cells can be assembled more cheaply than inorganic ones, none have yet shown efficiencies as high as those in silicon solar cells. To solve this problem, new molecules with higher efficiencies are needed. Higher efficiencies depend both on long carrier lifetimes to allow charge extraction and correct bandgap matching to allow carrier separation. In this project we have used pump-probe spectroscopy to characterize the excitation timescales and carrier lifetimes of a new electron donor molecule in combination with various acceptor molecules in solution. We have also discussed electron transfer mechanisms in the system.

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Fabrication of Flexible, Implantable Electrodes for *in vivo* Recording of Neural Activity

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In order to study the brain activity of living organisms, electrode arrays can be implanted into the brain and can determine the source of an electrical signal down to the firing of a single neuron. Commercial probes containing these arrays are available; however, most of these probes contain an inflexible silicon backbone. Because of the large discrepancy in flexibility between the silicon probe and the brain tissue, the probe is seen as a foreign object and is encapsulated during the body's immune response. In order to perform long term neural recordings, flexible materials that better match the Young's modulus of brain tissue must be used as the probe backbone. Such a probe was fabricated using a thin layer of Parylene C as the probe backbone material because of its high level of conformability. An array of eight electrodes made of a 100 micron layer of metal coated in the conducting polymer poly(3,4-ethylenedioxythiophene) doped with poly(styrene sulfonate) (PEDOT:PSS) were fabricated on top of the Parylene film. The probe was insulated using a layer of permanent, biocompatible photoresist, leaving only the electrode recording sites open to the brain tissue. After fabricating a stiff "shuttle" to insert the probe into the brain, the neural activity in a rat brain will be studied.

Controlled Self-Assembly of Metalated and Non-Metalated Peptidic Arrays

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Peptide-based compounds are desirable targets for the development of novel nano-materials due to their propensity to form self-assembled, supramolecular architectures. Short, aromatic peptides such as diphenylalanine (FF) exhibit particularly strong tendencies to self assemble; the FF dipeptide has previously been shown to form discrete, hollow nanotubes with persistent lengths on the order of microns [1]. Here, we have synthesized a diphenylalanine-based compound bearing two organic chelating groups capable of coordinating various transition metal ions such as Pt(II), Re(I), Rh(III), or Ru(II). We investigated the self-assembling behaviors of this peptide in coordination with several combinations of metals using Fourier transform infrared (FTIR) spectroscopy, circular dichroism (CD) spectroscopy, and scanning electron microscopy (SEM). SEM analysis showed both the non-metallated and diplatinum-metalated peptides formed naonofibers with less than 30 nm diameter. The IR and CD analyses did not indicate the formation of β-sheet structures, a conformation characteristic of diphenylalanine nanotubes, which suggests the structure of these fibers may distinct from those formed from diphenylalanine. The method for incorporating transition metals into peptide nanostructure described here may benefit future research involving the use of nano-scale structures in fields such as electronics of catalysis.

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