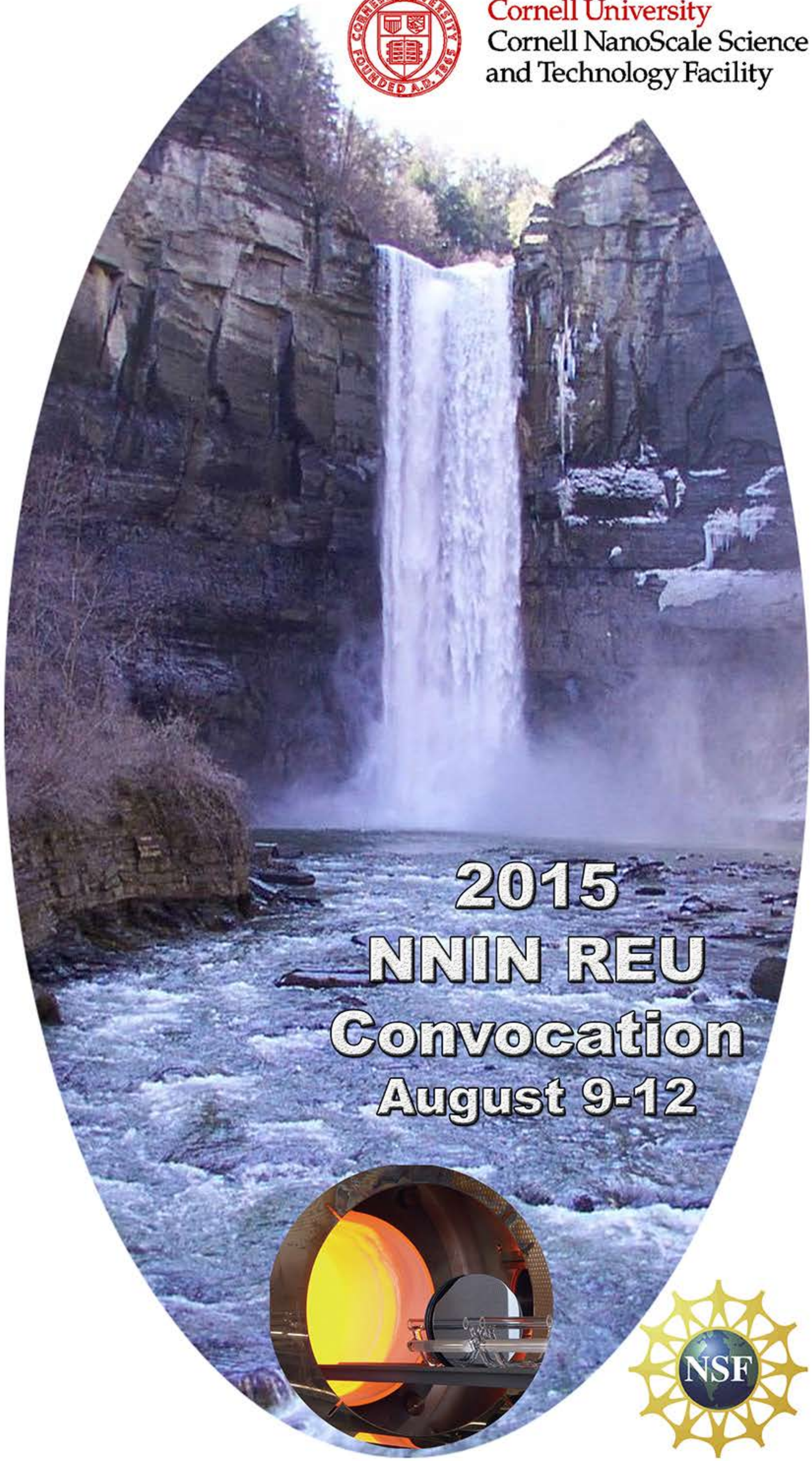
Cornell University
Cornell NanoScale Science and Technology Facility



2015 NNIN REU Convocation

August 9-12

2015 NNIN REU CONVOCATION

Cornell University, Ithaca, NY

OVERVIEW:

- **Interns have TWELVE minutes on the schedule**
- **Plenary Sessions are held in B17 Upson Hall**
- **Parallel Presentation Sessions will be given in 203 and 219 Phillips Hall**
- **The Poster Session & Reception will take place in the Duffield Hall Atrium**
- **All breakfasts are BEFORE the day's events** *(Interns at Becker House Dining Room and Staff at Best Western)*
- **Lunches and Dinners are as described each day**
- **Snacks will be available through-out the day in the presentation rooms**

•• SUNDAY •• AUGUST 9 ••

6:30 PM Welcome Pizza Party .. ..Hans Bethe House Dining Room

- **Food Provided By Cornell Dining**
- **Introducing NNIN REU Management**
- **Games/Packets/Presentation Uploading**

•• MONDAY •• AUGUST 10 ••

(Everyone has breakfast BEFORE the day's events begin)

8:45-9:10 a.m., Welcome.. .. .. .B17 Upson Hall

- **Don Tennant, CNF Director of Operations**
- **Lynn Rathbun, NNIN Deputy Director**

(Ten minutes for travel to the presentation rooms)

SESSION 203_A. .. ..203 Phillips Hall

SESSION 203_A, Session Chair: Nancy Healy

9:20-9:32, 203_A1 **Mr. Isaac Fuhrman** **page 12**
Crumpled Graphene Oxide-Polysulfone Composite Membranes for Water Purification

9:32-9:44, 203_A2 **Ms. Anisa Swei** **page 12**
Micropatterns and PDMS Microdevices for the Investigation of Cardiac Muscle Cell Structure and Function

9:44-9:56, 203_A3 **Mr. Victor Acero** **page 13**
Enhancement of High-Performance Graphene Biosensors for Cancer Detection

9:56-10:08, 203_A4 **Mr. Raymond Barakat** **page 13**
Tablet Analysis and Display of Semiconductor Biosensors

10:08-10:20, 203_A5 **Ms. Jyoti Campbell** **page 14**
Optimization of Thin Film Composite Polyamide Reverse Osmosis Membrane by Polyethylene Glycol for Enhanced Fouling Resistance

SESSION 219_A. .. ..219 Phillips Hall

SESSION 219_A, Session Chair: Joyce Allen

9:20-9:32, 219_A1 **Ms. Emilie Benson** **page 32**
Electrostatic Gating of MBE-Grown $NdTiO_3$ Thin Films

9:32-9:44, 219_A2 **Mr. Nathan Brooks** **page 32**
Image Reconstruction through Scattering Media using a Single-Pixel Camera

9:44-9:56, 219_A3 **Mr. Benjamin Carberry** **page 33**
Zinc Oxide Deposition Methods for Opto-Electronic Applications

9:56-10:08, 219_A4 **Mr. Yaset Evo** **page 33**
Nanoscale Light Emitting Diodes with Tunable Emission Colors

10:08-10:20, 219_A5 **Mr. Michael Valerino** **page 34**
Bandwidth Expansion for Lippmann-Bragg Holographic Photopolymers

10:20-10:50-Break

SESSION 203_B. .. ..203 Phillips Hall

SESSION 203_B, Session Chair: Kathryn Hollar

10:50-11:02, 203_B1 **Ms. Danielle Chase** **page 14**
Microfluidic Pipette Array for Single Cell Mechanics Studies

11:02-11:14, 203_B2 **Ms. Catherine Demos** **page 15**
Imaging Live DU145 Cancer Cells Using Scanning Probe Microscope

11:14-11:26, 203_B3 **Mr. Matthew Devlin** **page 15**
Exploration of Protein Capture Methods for Applications in Microfluidic Devices

11:26-11:38, 203_B4 **Ms. Christina Franke** **page 16**
Optimization of Nanoparticle Delivery to Plants: Do Nanoparticle Properties Affect Cellular Internalization?

11:38-11:50, 203_B5 **Ms. Michelle Galarneau** **page 16**
A Microfluidic Mimic of the Human Microvasculature

SESSION 219_B. .. ..219 Phillips Hall

SESSION 219_B, Session Chair: Michael Deal

10:50-11:02, 219_B1 **Mr. Brian Bemis** **page 34**
Design and Analysis of Nanoscale Resonators to be Integrated with Monolayer Heterostructures

11:02-11:14, 219_B2 **Ms. Kasia Gibson** **page 35**
Optical Resonant Frequency Detection System for Mass-Sensing MEMS Resonators

11:14-11:26, 219_B3 **Ms. Marilyn Mathew** **page 35**
Microfabrication and Testing of Directional Piezoelectric Microphones Using Aluminum Nitride

11:26-11:38, 219_B4 **Mr. Travis O'Neil** **page 36**
Optimum Sputtering Conditions for in situ Crystallization of PZT Thin Films on Flexible Metal Foil

11:38-11:50, 219_B5 **Mr. Zachary Schaffer** **page 36**
Design and Fabrication of Graphene on Nitride Accelerometer

12:00-1:30p, Lunch and Site Photographs as Assigned

- **WE WILL START WITH THE GROUP PHOTO BEFORE FOOD**
- **PLEASE STAY IN BAUM and LISTEN FOR YOUR SITE**

1:30-3:00-Second Year Program, Dr. Lynn Rathbun .. .. .B17 Upson Hall

(Ten minutes for travel to the presentation rooms)

SESSION 203_C . .. .203 Phillips Hall

SESSION 203_C, Session Chair: Michelle Chavis

3:10-3:22, 203_C1 **Mr. Jacob Heppner** **page 17**
High-Throughput Fabrication of Nanofluidic Biosensors

3:22-3:34, 203_C2 **Mr. Joseph Hittinger** **page 17**
Optimization & Characterization of Gold Nanoparticle-DNA Conjugate Devices

3:34-3:46, 203_C3 **Ms. Bilan Yang** **page 18**
Graphene Fabrication with a Motorized Linear Stage Based on "Scotch Tape" Method

3:46-3:58, 203_C4 **Mr. Adam Kunesh** **page 18**
The Wrinkling of Thin Elastic Membranes as a Cancer Diagnostic

3:58-4:10, 203_C5 **Ms. Abigail Magee** **page 19**
Fabrication and Design of EGFET Devices for Biosensing

4:10-4:22, 203_C6 **Ms. Tayler Pauls** **page 19**
Nanoplasmonic Biosensing Microfluidics for Immune Status Monitoring of Critically-Ill Children

SESSION 219_C . .. .219 Phillips Hall

SESSION 219_C, Session Chair: Kathy Gehoski

3:10-3:22, 219_C1 **Ms. Robyn Collette** **page 37**
Determining the Spin Hall Angle of Gadolinium

3:22-3:34, 219_C2 **Mr. Yasunori Kutsuma** **page 37**
Fundamental Studies of the Synthesis of Graphene Using the PECVD Process

3:34-3:46, 219_C3 **Mr. Michael Statt** **page 38**
The Optimization of Thin Film Molybdenum Disulfide Synthesis

3:46-3:58, 219_C4 **Mr. Yuichi Tsujiura** **page 38**
Improvement of Sodium-Ion Batteries Using Solution-Grown Germanium Nanowire Anodes

3:58-4:10, 219_C5 **Ms. Margot Hultz** **page 39**
Surface Adsorption and Enzymatic Hydrolysis of Polyphosphates;
Implications for Understanding Phosphorus Cycling

4:10-4:22, 219_C6 **Ms. Mary Alsobrooks** **page 39**
Vanishing Programmable Resources: Design, Materials, and Characterization

4:22-4:30, Wrap Up and Dinner Plan.. .. .. *in presentation rooms*

5:30-8:00, Picnic on the Engineering Quad

- **BBQ provided by Catering By Ithaca Bakery (Baum Atrium)**

•• TUESDAY •• AUGUST 11 ••

8:30-8:45 a.m., Welcome & Announcements .... ***in presentation rooms***

SESSION 203_D..203 Phillips Hall

SESSION 203_D, Session Chair: Wendy Ibsen

8:45-8:57, 203_D1 **Ms. Erin Rousseau** **na**
Currently Unavailable per Principal Investigator

8:57-9:09, 203_D2 **Mr. Brian Ryu** **page 20**
A High-Throughput Image-Processing Based Analysis
of Dynamic Cell Surface Interactions in a Microfluidic Chip

9:09-9:21, 203_D3 **Mr. Alejandro Sanchez** **page 21**
High-Throughput Drug Screening in vivo Using Droplet Microfluidics

9:21-9:33, 203_D4 **Mr. Cyrus Thompson** **page 21**
Development of Dual-Modality Nanoparticles for PET/MR

9:33-9:45, 203_D5 **Mr. Shaun Engelmann** **page 22**
Research in a New Diagnostic Tool for Light Chain Amyloidosis

9:45-9:57, 203_D6 **Ms. Jade Fostvedt** **page 22**
Infiltration, Imidization, and Cross-Linking of Polyimides in Molecular-Scale Confinement

SESSION 219_D..219 Phillips Hall

SESSION 219_D, Session Chair: Sandrine Martin

8:45-8:57, 219_D1 **Mr. Bryan Brasile** **page 40**
Simulation and Nanofabrication for Tip-Enhanced Raman Spectroscopy

8:57-9:09, 219_D2 **Ms. Nermina Brljak** **page 40**
Electric Field-Directed Assembly of Nanowires on Patterned Electrodes

9:09-9:21, 219_D3 **Ms. Molly Enenbach** **page 41**
Fabrication of Test Samples for Calibration and Testing in Three-Dimensional Super Resolution Microscopy

9:21-9:33, 219_D4 **Mr. Abbas Furniturewalla** **page 41**
A Suspended Heater Wire for Low Power Gas Sensing Using the 3-Omega Technique

9:33-9:45, 219_D5 **Ms. Emily MacDonald** **page 42**
Part 1: Nanofabrication and Characterization of Quasi-Crystal Metasurfaces using Shadow-Sphere Lithography

9:45-9:57, 219_D6 **Ms. Caroline Zellhofer** **page 42**
Part 2: Nanofabrication and Characterization of Quasi-Crystal Metasurfaces using Shadow-Sphere Lithography

9:57-10:30, Break

SESSION 203_E . . . . .203 Phillips Hall

SESSION 203_E, Session Chair: Marylene Palard

10:30-10:42, 203_E1 **Mr. Harold Fu** **page 23**
Optical Characterization of AlInAsSb Digital Alloy Films

10:42-10:54, 203_E2 **Mr. Masashi Fukuzawa** **page 23**
Advanced Dielectrics for Microelectronics: Chemically Amplified, Low-k Materials

10:54-11:06, 203_E3 **Mr. Tom George** **page 24**
Ultrathin, Smooth, and Stable Doped Silver Films

11:06-11:18, 203_E4 **Mr. Justin Goodwill** **page 24**
Optimizing Contact Resistance to MoS_2 for Improved Device Performance

11:18-11:30, 203_E5 **Ms. Sophia Hu** **page 25**
Aluminum-Induced Crystallization of Silicon Thin Films on Flexible Glass Substrates

11:30-11:42, 203_E6 **Mr. Nathan Huber** **page 25**
Enhanced Mobility in a SiO_2 Capped 2DEG at $SrTiO_3$ (100) Surface

SESSION 219_E . . . . .219 Phillips Hall

SESSION 219_E, Session Chair: Nathan Reed

10:30-10:42, 219_E1 **Ms. Lorelis González López** **page 43**
Diblock Copolymers for Diamond Patterning and Applications

10:42-10:54, 219_E2 **Ms. Alin Miksi Kalayjian** **page 43**
Designing a Conjugated Polymer Consisting of Phenyl-oxazole Derivatives Using C-H/C-O Coupling

10:54-11:06, 219_E3 **Mr. Christopher Phenicie** **page 44**
Diverse Patterns and Geometries in Self-Assembled Block Copolymer Thin Films Through Multilayer Mixing

11:06-11:18, 219_E4 **Ms. Elyse Pizzella** **page 44**
Synthesis and Characterization of Size- and Shape-Specific Gold Nanocrystals for Superlattice Assembly

11:18-11:30, 219_E5 **Ms. Claire West** **page 45**
Magnetic Fano Interferences in Plasmonic Metal Oligomers

11:42-1:30, Lunch

- **Meal Tickets for Mattin's Café and Sage Hall Café (No seating reserved! Sit where you like.)**

SESSION 203_F . .. .203 Phillips Hall

SESSION 203_F, Session Chair: Tomoko Borsa

1:30-1:42, 203_F1 **Ms. Janay Frazier** **page 26**
Fabrication of Diamond Ultraviolet Light Emitting Diodes

1:42-1:54, 203_F2 **Ms. Rachel Miller** **page 26**
Optimizing Hard Mask Etching for Quartz Nano-Devices

1:54-2:06, 203_F3 **Ms. Anoosha Murella** **page 27**
Minimizing Losses in TiO_2 Thin-Film Waveguides for Nanophotonic Applications

2:06-2:18, 203_F4 **Mr. Philip Zurek** **page 27**
High-Efficiency Broadband Lippmann-Bragg Reflection Holograms

2:18-2:30, 203_F5 **Mr. Scott Blankenbaker** **page 28**
Fabrication of Bio-Inspired Photonic Structures for Antireflectivity in Cadmium Telluride Infrared Detectors

2:30-2:42, 203_F6 **Mr. Corey Kwok** **page 28**
In Fiber Flow Rate Sensors using Thermally Drawn Multi-Material Fluidic Channel Fibers

SESSION 219_F . .. .219 Phillips Hall

SESSION 219_F, Session Chair: Mr. James Marti

1:30-1:42, 219_F1 **Ms. Taylor Soucy** **page 45**
Measurement and Management of Thin Film Stresses

1:42-1:54, 219_F2 **Ms. Anna Smith** **page 46**
Conformation of Organic Electronics to the Hemispherical Shape Using Elastomeric Transfer Elements

1:54-2:06, 219_F3 **Mr. Andrew King** **page 46**
Atomically Thin Films: Fabrication and Real-Time Electrical Characterization

2:06-2:18, 219_F4 **Ms. Elizabeth Lee** **page 47**
Magneto-Optic Characterization of Ferromagnetic Thin Films for Use in Nano-Scale Computer Applications

2:18-2:30, 219_F5 **Mr. Quang Nguyen** **page 47**
Multidimensional Metal-Dielectric Plasmonic Array

2:30-2:42, 219_F6 **Ms. Veronika Werner** **page 48**
Study of Quantum Confined Nanostructures at Low Temperatures with Opto-Electronic Measurements

2:42-3:00, Break

3:00-4:30-Careers in Nanotechnology Panel Discussion .. .. .B17 Upson Hall

TUESDAY EVENING EVENT:

6:00-8:30, Sciencenter, http://www.sciencenter.org/

- **5:30p, Buses to Sciencenter**
- **ASSEMBLE at BAKER FLAG POLE at 5:15PM — ATTENDANCE WILL BE TAKEN!**
- **Middle Eastern Dinner at the Sciencenter**
- **8:30, Buses back to BAKER FLAG POLE**

•• WEDNESDAY •• AUGUST 12 ••

8:30-8:45 a.m., Welcome & Announcements .. .. in presentation rooms

SESSION 203_G. .. ..203 Phillips Hall

SESSION 203_G, Session Chair: Jameson Wetmore

8:45-8:57, 203_G1 **Mr. Raul Flores** **page 29**
Fabrication of All-Aluminum p-Type Silicon Solar Cells

8:57-9:09, 203_G2 **Ms. Cristina Guillen** **page 29**
Fabrication of Light Emitters and Photovoltaic Cells with GaAs Nanowires on Metal Substrates

9:09-9:21, 203_G3 **Mr. Alexander Rosner** **page 30**
Evaluation of TiO_2 as Carrier Selective Contact for High Efficiency Photovoltaic Applications

9:21-9:33, 203_G4 **Mr. Yusuke Hayashi** **page 30**
Graphene/III-V Electro-Optic Hybrid Devices

9:33-9:45, 203_G5 **Ms. Andrea Randolph** **page 31**
Graphene Junction Field Effect Transistors on a Silicon Carbide Substrate

9:45-9:57, 203_G6 **Mr. Joshua Bostwick** **page 31**
High Aspect Ratio Dry Etching of Gallium Nitride

SESSION 219_G. .. ..219 Phillips Hall

SESSION 219_G, Session Chair: Karl Bohringer

8:45-8:57, 219_G1 **Mr. Joshua Alden** **page 48**
Temperature Dependence of Carbon Nanotube Growths

8:57-9:09, 219_G2 **Ms. Stephanie Pastor** **page 49**
Delta-Doping of Diamond

9:09-9:21, 219_G3 **Ms. Tanaka Benton** **page 49**
Growth of Graphene by Silicon Carbide Sublimation

9:21-9:33, 219_G4 **Ms. Mikayla Essigmann** **page 50**
Smart-Cut Processing for Transfer of High-Temperature Ceramic Materials to Silicon

9:33-9:45, 219_G5 **Mr. Scott Chow** **page 50**
Engineering the Fixed Charge of Al_2O_3 for Field-Assisted Passivation in Heterojunction Solar Cells

9:45-9:57, 219_G6 **Mr. Isaac DiGennaro** **page 51**
Mechanical Testing of Flextrode: An ITO-Free, Transparent, Polymer Based Electrode

9:57-10:30, Break

10:30-12:00, SEI of Nanotechnology Discussion. .. .. .B17 Upson Hall

- **Jameson Wetmore, Arizona State University**

12:00-1:30p, Lunch. .. .. Buffet in Statler Ballroom

1:30-2:00, Set Up Poster Session in Duffield Atrium

2:00-4:00, Poster Session & Reception, Duffield Hall Atrium

- **All posters up. Please spend 60 minutes at your poster!**

4:00-4:30, Wrap Up, Atrium

- **Melanie-Claire & Lynn Rathbun**

The evening is free — no plans for interns

•• THURSDAY •• AUGUST 13 ••

PLEASE PAY CLOSE ATTENTION TO THE DEPARTURE SCHEDULE

EVERYONE MUST CHECK OUT BY 10:00 AM

2015 NNIN iREU Abstracts

National Nanotechnology Infrastructure Network

Research Experience for Undergraduates

Program

2015

CONVOCATION ABSTRACTS

in order of room & presentation

Crumpled Graphene Oxide-Polysulfone Composite Membranes for Water Purification

Isaac Fuhrman
Mechanical Engineering, University of Nebraska-Lincoln

NNIN REU Site: Nano Research Facility, Washington University in St. Louis, St. Louis, MO
NNIN REU Principal Investigator: Dr. John Fortner, Energy, Environmental and Chemical Engineering, WUSTL
NNIN REU Mentor: Yi Jiang, Energy, Environmental and Chemical Engineering, Washington University in St. Louis
Contact: isaacokoboji@gmail.com, jfortner@wustl.edu, jiang.y@wustl.edu

Previously, Crumpled Graphene Oxide (CGO) has been layered on surfaces of commercial water treatment membranes to increase water flux as well as increase antimicrobial properties. This study explores CGO's effects on flux, rejection, fouling, and antifouling properties when structurally incorporated into polysulfone (PSF) membranes. Different ratios of CGO were added into the casting solution for a phase-inversion process. The synthesized membranes were then tested in an effort to optimize CGO mass loadings. Consistently, water flux for CGO membranes was higher than the pristine counterparts with a similar rejection of a model foulant Bovine Serum Albumin (BSA). Flux and rejection were found as high as 100 L/m^2 h bar and 90% of BSA respectively. The enhanced performance was attributed to the membranes' structure and morphology, which had CGO exposed on the membrane surface. It is hypothesized that these surface openings served as water channels through the selective surface toward the more porous region of the membrane, creating higher flux.

Micropatterns and PDMS Microdevices for the Investigation of Cardiac Muscle Cell Structure and Function

Anisa Swei
Biomedical Engineering, Worcester Polytechnic Institute

NNIN REU Site: Cornell NanoScale Science and Technology Facility, Cornell University, Ithaca, NY
NNIN REU Principal Investigator: Jan Lammerding, Weill Institute for Cell and Molecular Biology, Cornell University
NNIN REU Mentors: Patricia Davidson and Gregory Fedorchak, Weill Institute for Cell and Molecular Biology, Cornell
Contact: aswei@wpi.edu, jan.lammerding@cornell.edu, patricia.davidson@cornell.edu, grf44@cornell.edu

Mutations in proteins dedicated to surrounding the genetic material in cells can lead to dilated cardiomyopathy, a progressive increase in the size of the heart that ultimately results in heart failure; nonetheless, the exact mechanism by which the mutations cause this cardiac disease is not yet understood. One hypothesis is that these mutations interfere with heart muscle cell organization and/or the exertion of contractile forces, which are essential for these cells to properly function. The focus of this project is to design two microfabricated polydimethylsiloxane (PDMS) devices that will (a) assess the contractile forces generated and (b) examine the structural alignment, comparing healthy and mutant human cardiac cells. The first device consists of flexible PDMS micropillars, ranging in sizes and center-to-center distances. Cells exerting forces on the pillars will flex them, allowing the quantification of cardiac cell contractile forces. The second device is composed of PDMS stamps to pattern cell adhesion molecules onto substrates to control cell shape and observe cytoskeleton alignment in various rectangular shapes, differing in length-to-width ratios. The devices were fabricated using photolithography techniques to produce SU-8 wafers, which are then used as molds to generate PDMS devices. Using these devices, we were able to optimize methods for measuring pillar deflection and observing cellular structure and alignment. Ultimately, a better understanding of how these mechanical properties become affected by the disease-causing mutations will provide improved insights into the disease mechanism.

Enhancement of High-Performance Graphene Biosensors for Cancer Detection

Victor Pablo Acero
Engineering Science, The Pennsylvania State University

NNIN REU Site: Minnesota Nano Center, University of Minnesota-Twin Cities, Minneapolis, MN
NNIN REU Principal Investigator: Tianhong Cui – Mechanical Engineering – University of Minnesota
NNIN REU Mentor: Shota Sando – Mechanical Engineering – University of Minnesota
Contact: acero002@umn.edu ssando@umn.edu cuixx006@me.umn.edu

Current Alpha-fetoprotein (AFP) sensing technologies such as ELISA require a lot of equipment, time, and skill. Still, it would be less sensitive then our proposed graphene biosensors, which in theory could detect a single AFP. Graphene's unique material properties and sensitivity to the surrounding environment are exploited in our sensor for the detection of AFP. A U-shaped gold electrode containing a small gap for the sensing area would then be patterned using photolithography. The gap would be closed by covering the bare substrate with our few-layer-graphene (FLG) structure. We tune the thickness, and thus the properties, of graphene through a unique layer-by-layer self-assembly process which uses graphene solution and polyelectrolytes. The graphene sensing area is further prepared with poly-l-lysine and then functionalized with anti-AFP. Also, due to the fact that the ability to detect AFP is heavily limited by the signal-noise ratio, we redesigned the basic interface between gold and graphene in multiple ways to achieve a better signal-noise ratio in our sensors. The sensors that were fabricated were successful in detecting alpha-fetoprotein even in concentrations as low as 1 pg/ml. Lastly, the redesigned gold/graphene interface showed promising results and seems to have only been limited by our fabrication procedure.

Tablet Analysis and Display of Semiconductor Biosensors

Raymond Barakat
Electrical Engineering, Arizona State University

NNIN REU Site: Microelectronics Research Center, The University of Texas, Austin, TX
NNIN REU Principal Investigator: Prof. Ray Chen, Electrical and Computer Engineering, University of Texas at Austin
NNIN REU Mentor: Dr. Swapnajit Chakravarty, Omega Optics-Austin, Texas
Contact: rjbaraka@asu.edu, chen@ece.utexas.edu, swapnajit.chakravarty@omegaoptics.com

Photonic crystals using Silicon on Insulator (SOI) processes have applications as extremely sensitive biosensors. By taking advantage of the photonic bandgap (PBG), light can be guided through the photonic crystal (PC) using PC micro-cavities to block light and PC waveguides to allow light through. When light shines through the PC biosensor, depending on the design, the output spectrum will display distinct resonances. Then a sample is pipetted on the PC biosensor and a wavelength shift is observed. The goal of this project is to develop software in MATLAB which quickly collects and analyzes spectrum data received from the biosensor. The software is also able to control a near-infrared SLED light source in order to perform repeated scans and analyses on data collected from an optical spectrum analyzer (OSA). This software will run on a tablet in order to explore the feasibility of a portable biosensing platform. Tests were performed on a biosensor using the 2A81G5 antibody as a probe in order to detect cadmium ions in solution. Current work is being done to refine the software suite we have developed, such as improving the accuracy of resonance detection and tracking.

Optimization of Thin Film Composite Polyamide Reverse Osmosis Membrane by Polyethylene Glycol for Enhanced Fouling Resistance

Jyoti Campbell
Chemistry, Wellesley College

NNIN REU Site: Nano Research Facility, Washington University in St. Louis, St. Louis, MO
NNIN REU Principal Investigator: Dr. Young-Shin Jun, Energy, Environmental, and Chemical Engineering, WUSTL
NNIN REU Mentor: Zongsen Zou, Energy, Environmental, and Chemical Engineering, WUSTL
Contact: jcampbe5@wellesley.edu, ysjun@wustl.edu, zou.zongsen@wustl.edu

Water scarcity is a serious concern for the world. Water desalination is an important process to generate fresh water to alleviate water scarcity, especially in water stressed regions, and it will continue to grow in importance. Thin film composite polyamide (TFC-PA) reverse osmosis (RO) membranes are commonly used by desalination plants. However they commonly experience fouling, which can decrease water flux and salt rejection. Polyethylene glycol (PEG) is a hydrophilic material that, when attached to the membrane surface, can increase membrane flux by making the surface more hydrophilic. In this study, a commercially available TFC-PA membrane (BW30) was modified to investigate the effect of this modification on mineral ($CaSO_4$ and $CaCO_3$) and organic (humic acid) fouling. In particular, water flux and salt rejection were tested. The surface property and the extent of membrane fouling were examined by contact angle analysis and scanning electron microscopy, respectively. The results indicate that the PEG-modified membrane performs better under relatively low influent foulant concentrations, but performs similarly to the PA membrane for very high influent foulant concentration (higher than seawater concentration). This suggests that for influent water with lower foulant concentrations, the PEG modification is beneficial for long term membrane use.

Microfluidic Pipette Array for Single Cell Mechanics Studies

Danielle Chase
Mechanical Engineering, University of Minnesota

NNIN REU Site: Lurie Nanofabrication Facility, University of Michigan, Ann Arbor, MI
NNIN REU Principal Investigator: Allen Liu, Mechanical Engineering, University of Michigan
NNIN REU Mentor: Lap Man Lee, Mechanical Engineering, University of Michigan
Contact: chase230@umn.edu, allenliu@umich.edu, melmlee@umich.edu

Many pathological and physiological processes of human disease are mediated by cell mechanics. The study of cell mechanics requires micro-engineered tools to apply a localized force and make precise physical measurements. Micropipette aspiration is a classical tool used for mechanical analysis of single cells, and several cell mechanical properties, including membrane tension, can be measured by studying cell deformation. This technique, however, is limited by its low throughput and requires highly specialized training in practice. Recently, our lab has developed a microfluidic device based on multilayer polydimethylsiloxane (PDMS) soft-lithography to study single cell mechanics in an automatic and parallel manner. Through the manipulation of volume flow rates, this device is able to trap and apply a precise pressure difference across single cells. We incorporated a flow control layer in an effort to improve the trapping efficiency of single cells, and carried out experimental and simulation studies to characterize the device. This novel microfluidic device can be used to measure the cell stiffness of metastatic human breast cell lines in comparison with their healthy counterparts. The ability to use microfluidic pipette aspiration for high throughput mechanophenotyping will enable potential clinical applications.

Imaging Live DU145 Cancer Cells Using Scanning Probe Microscope

Catherine Demos
Bioengineering, Clemson University

NNIN REU Site: Howard Nanoscale Science and Engineering Facility, Howard University, Washington, DC
NNIN REU Principal Investigator: Tina Brower-Thomas, PhD, Chemical Engineering, Howard University
Contact: cdemos@clemson.edu, tina.browerthomas@howard.edu

Different cells in the body have unique surface proteins which all conduct electricity. Cell electrophysiology could be the key to differentiating cancerous cells from healthy cells in vivo. Silicon carbide (SiC) is a biocompatible, chemically inert, thermally stable, conductive material on which we have tested the viability of DU145 cells. It is capable of conducting a voltage so as to detect differences in cells via Current-Sensing Atomic Force Microscopy (CSAFM). We set up a flow cell for Agilent Technologies 5500 AFM to examine the living DU145 cells in media, with a bias applied. A parallel part of this experiment is to develop a way to functionalize the SiC surface to achieve specificity when attaching cells, to confirm that the CSAFM method of identification is successful. After cleaning, an oxide layer is formed on the surface, then 3-aminopropyltriethoxysilane (APTES) is attached to result in terminal amine groups on the SiC. This creates a surface amenable to protein attachment followed by antibody attachment, which is the key to binding specific cells in specific areas of the substrate.

Exploration of Protein Capture Methods for Applications in Microfluidic Devices

Matthew Devlin
Biomedical Engineering, Georgia Institute of Technology

NNIN REU Site: Cornell NanoScale Science and Technology Facility, Cornell University, Ithaca, NY
NNIN REU Principal Investigator: Haiyuan Yu, Department of Biological Statistics and Computational Biology, Cornell
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On-chip protein immunoprecipitation is often a substantial limitation in the continued development of microfluidic tools for detecting protein-protein interactions in high throughput. Though adaptable surface chemistry on glass and PDMS lend themselves to robust, on-chip protein immobilization, problems such as non-specific protein adsorption, rigorous washing conditions, and low protein synthesis yields readily diminish assay sensitivity in protein interaction screens. In an effort to improve on-chip protein expression levels, we explored various chip-protein conjugation methods such as antibody crosslinking via (3-Aminopropyl)triethoxysilane-derivatized surfaces, Protein A-conjugated surfaces, as well as streptavidin-biotin coated surfaces. Increasing sensitivity to expressed protein was also explored through varying concentrations of both capture and probe antibodies as well as through the adjustment of enzyme-conjugated or fluorescently-labelled probe antibodies. Through our protein surface conjugation experiments, we are able to successfully synthesize and capture protein on-chip. Continued development towards quantifying the binding strengths of protein-protein interactions would be extremely beneficial not only for the field of cellular proteomics, but could also have applications towards testing how drugs or other chemical agents modulate protein interactions.

Optimization of Nanoparticle Delivery to Plants: Do Nanoparticle Properties Affect Cellular Internalization?

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The use of agrochemical-nutrient fertilizers has endured much scrutiny in recent years due to concerns that they damage the ecosystem and endanger public health. To minimize the risk, intervention of nanotechnology in agriculture is increasing in the form of nanofertilizers, nanopesticides, and nanosensors, believed to enhance profitability and sustainability in the farmer practices. However, much more development is needed before the broader scale use of nanotechnology in the agricultural sector is a reality. Aerosol delivery of nanoparticles may help to reduce environmental implications by increasing uptake by plants, thus lessening the need for repeated applications, as well as by limiting contamination of the soil environment. The purpose of this work was to study the effects of various gold nanostructures of 30 to 80 nm delivered by aerosol application on uptake, translocation, and accumulation in a watermelon plant. Cellular uptake and accumulation of gold nanoparticles was confirmed by Transmission Electron Microscopy (TEM) and Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS). Observations suggested that nanoparticles could uptake by direct penetration and stomatal opening. Translocation of nanoparticles from leaf to root evidenced that nanoparticles travel by the phloem transport mechanism. Accumulation and transport of nanoparticles depends on nanoparticle shape and plant tissues.

A Microfluidic Mimic of the Human Microvasculature

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The major cause of morbidity and mortality in sickle cell disease, a genetic disorder caused by a DNA mutation, is the vaso-occlusive crisis (VOC). In a VOC, the flow of blood becomes obstructed in the microvasculature under hypoxic conditions. Currently, hydroxyurea (HU) is the sole FDA-approved drug treatment option available to patients, and yet HU is ineffective in one-third of those treated. Moreover, there is a clear need for more effective drug treatments, as well as a screening platform to evaluate drug efficacy. Because drug efficacy is intimately linked with the occurrence of VOCs, we sought to create an in vitro disease model that accurately replicates the physiological parameters found in VOCs. To accomplish this, we built a microfluidic device that mimics the physiological vessel architecture and oxygen concentration gradient between blood and the surrounding tissue. We used AutoCAD to design the device layers and soft photolithography to fabricate the masters. We then cast the masters with polydimethylsiloxane (PDMS) to create a dual-layer device that diffusively couples the oxygen gradient to the microvasculature layer. Ultimately, this device will act as a drug-screening platform with the goal of expanding and enhancing treatment options for patients suffering from sickle cell disease.

High-Throughput Fabrication of Nanofluidic Biosensors

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Surface Plasmon Polaritons (SPPs) are propagation of electromagnetic fields across a metal-dielectric interface and are commonly excited through the coupling of light to a metallic surface. Plasmonic waveguides, such as a nanogap between two metals, grooves in a metal surface, or a thin metallic film surrounded by dielectric material, can be used to guide SPP's beyond the conventional diffraction limit of light, allowing for optical measurements that would not be possible with standard techniques. Linear and annular nanogaps will be fabricated to utilize plasmonic phenomenon such as surface enhanced infra-red absorption, surface plasmon resonance, and extraordinary optical transmission. These techniques allow us to sense small changes in the absorption or reflection spectra of the device or refractive index of the surrounding medium and spectroscopically detect compounds within close proximity to our structures. Increased device sensitivity will hopefully be shown through the reduction of critical dimensions.

Optimization & Characterization of Gold Nanoparticle-DNA Conjugate Devices

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Gold nanoparticles (AuNP) have been broadly studied as platforms for small molecule, antibody, and aptamer delivery to cells because of the wide variety of functional groups that can be bound to the AuNP surface. Many reports of AuNP applications in biomedical diagnostics and therapeutics lack sufficient characterization to fully understand and optimize their loading. In this project, spherical AuNP were loaded with deoxyribonucleic acid (DNA) oligonucleotides to make a series of single- and double-stranded conjugates, which were characterized via various established methods to optimize loading efficiency and functionality. Characterization methods used include Ultraviolet-Visible Spectrophotometry to measure absorbance and estimate loading efficiency; Dynamic Light Scattering and Zeta Potential measurements to estimate conjugate size and extent of aggregation; and gel electrophoresis to separate and analyze conjugates based on size and charge. Toehold-mediated strand displacement DNA fluorescent gates were tested in order to relate characterization to device performance. Salt aging to 100mM NaCl provided high loading (131 ± 7 strands per particle) with low particle aggregation and relatively high hybridization efficiency ($58 \pm 6\%$). Achieving optimal loading of the AuNP-DNA conjugates while balancing device performance can provide greater functionality for applications, such as high payload drug delivery agents.

Graphene Fabrication with a Motorized Linear Stage Based on "Scotch Tape" Method

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Graphene, a single layer of graphite and an allotrope of carbon in the form of a two-dimensional lattice, became widely known as an excellent conductor of electricity and heat with its outstanding electronic transport system. The so-called "Scotch tape" method is among one of the easiest method to make graphene from graphite. When the Scotch tape with tiny flakes of graphite attached is folded and peeled several times, thinner layer of graphite is produced and finally becomes a single layer of carbon atoms of graphene. The purpose of this project is to develop a systematic approach using a motorized linear stage to cleave graphite into graphene in consistent patterns on Scotch tape that can give as many and large area of graphene as possible. With one piece of Scotch tape secured on the motorized stage and a graphite attached piece on a fixed manual stage, the computer sends commands to the controller and thus activates actuators to move in any of x, y, and z directions, which resembles the process of "peeling" and "folding." The resulted grey blocks of relatively thin layers of graphite can contain graphene visible through optical microscope when being pressed onto a SiO_2-covered wafer.

The Wrinkling of Thin Elastic Membranes as a Cancer Diagnostic

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Cell locomotion is dependent on the forces a cell exerts on its exterior environment, called cell traction forces. When this exterior environment consists of an ultra-thin elastic membrane, these traction forces result in significant wrinkling of the surrounding membrane.

As a cell attempts to draw the ultra-thin membrane toward localized focal points (located on the outer cell membrane), the angular component of the stress in the neighborhood about the cell becomes negative. This angular compression results in a localized buckling of the membrane. Cancer cells produce distinctly different forces from healthy cells, generating signature wrinkle patterns. The focus of this project is to analyze and fabricate a relatively expansive membrane and characterize the wrinkles produced by bladder cancer cells.

Membranes as thin as 150 nanometers were fabricated and characterized with wrinkle patterns generated by cancer cells. Fabrication was achieved via spinner. By controlling the concentration of the applied uncured elastic polymer, membrane thickness was varied. Cancerous cells were incubated on these membranes, resulting in the induction of wrinkle patterns. These wrinkle patterns were examined using a standard inverted microscope. This study evaluates the wrinkle patterns produced by cancerous cells for a portable point-of-care biosensor.

Fabrication and Design of EGFET Devices for Biosensing

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Ion sensitive field effect transistors (ISFET) measure the presence of ions within a solution via their effect on current flow within the device. The ionic charges induce the presence of charges within the device across the capacitive dielectric layer. The extended gate field effect transistor (EGFET) is more suitable for continuous monitoring in harsh environments, since the sensing area is external to the transistor. While the EGFET's sensing area is physically remote, the principles of operation remain the same. This project focuses on design and fabrication of EGFETs with different sensing membranes and geometries. The systematic investigation of the device parameters enables informed designs for increased sensitivity to pH. The devices are fabricated with chrome/gold electrodes and either a silicon nitride or silicon dioxide sensing area. The devices are tested with pH buffer solutions to provide consistent pH samples. However, we found the large variations in the components of the buffers resulted in inconsistent behavior, so we are also testing with titrated solutions. Initial testing determined the silicon nitride layer had poor quality, resulting in etching of the electrode and poor characterization.

Nanoplasmonic Biosensing Microfluidics for Immune Status Monitoring of Critically-Ill Children

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Rapid point of care diagnosis during any infection or disease can be critical for treatment decisions. A portable, real time, label free system is desirable, but not yet a reality in clinical and laboratory settings. A PDMS microfluidic device containing cross-linked polyethylene glycol (PEG-gel) features that facilitate individual cell capture is proposed as a viable option. Using the localized surface plasmonic resonance (LSPR) of gold nanorods to detect concentrations of specific cytokines to provide information on the status of the immune system was previously demonstrated and this sensing platform can be implemented into this new device. Preliminary results indicate that PEG-gel features can successfully be patterned on glass slides, but single cell capture with antibody has not yet been successful on the desired features. Multiple cell capture on large features of PEG-gel patterned on PDMS and glass is successful as well as double cell capture on 50 µm diameter PEG-gel features on glass slides. Future directions include the use of fluorescent antibodies to visualize and quantify antibody presence in the PEG-gel, robust PEG-gel patterning onto PDMS, successful single-cell capture, and ultimately integrating the PDMS/PEG-gel device with the LSPR gold nanorod cytokine detection system to observe and monitor immune cell behavior.

CURRENTLY UNAVAILABLE PER PRINCIPAL INVESTIGATOR

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A High-Throughput Image-Processing Based Analysis of Dynamic Cell Surface Interactions in a Microfluidic Chip

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Immunoaffinity-based lab-on-a-chip technologies offer high-throughput, label-free methods of cell characterization and are attractive for developing low cost point-of-care devices for cellular diagnostics. A biologically functionalized microfluidic channel would allow for detection of cells of particular interest, such as cancer cells as different cells have varying levels of affinity for different antibodies. This project focused on the development of a high-speed image-based analysis method combined with a microfluidic platform to identify cells using surface affinities of plasma membranes. A serpentine microfluidic channel was designed and constructed with polydimethylsiloxane (PDMS) using standard soft lithography methods. The microfluidic channel was partially functionalized with different coatings including poly-L-lysine (PLL), a positively charged amino acid polymer that electrostatically attracts the negatively charged plasma membrane of cells. The motion of cells passing through the channel was captured before and after moving through the PLL-coated region using a high-speed camera. A custom image processing software was developed and used to analyze and compare velocity profiles of cells and neutral particles that are similar in size. The developed platform can be used to study the dynamics of cell surface antigens and functionalized microfluidic devices. We expect such a technology will be very useful in designing and characterizing biomedical microsystems optimized to detect certain diseases.

High-Throughput Drug Screening *in vivo* Using Droplet Microfluidics

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High-throughput droplet emulsions under controlled flow conditions and drug concentrations provide a way of screening ~10^7 independent cell-in-drug micro chamber reactions in one day. We use a bilayer polydimethylsiloxane (PDMS) microfluidic device that generates a drug gradient by serial mixing in microchannels within one layer and another layer for creating picoliter-sized water-in-oil emulsions where the drug at different concentrations and lymphoblast cancer cells are encapsulated in a droplet in parallel. The focus of this project is to develop a platform to screen chemotherapeutic drugs at different doses on cancer cell lines at high throughput using (a) live/dead cell assay, (b) a fluorescent dye as indicator of drug concentration, and (c) photomultiplier tubes (PMT) for readout for both drug concentrations and cell state within each droplet. This allows us to rapidly screen for candidate drugs by quantifying their efficacy at distinct concentrations in killing cancer cells as function of time with high statistical resolution. The novelty of high-throughput droplet microfluidics in drug screening is the capability of decreasing time for analysis, volumes of reagents, and cost using PDMS microfluidic technology, while increasing the number of quantified interactions in comparison to conventional drug screening.

Development of Dual-Modality Nanoparticles for PET/MR

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Behind strong medical treatments lie accurate diagnostics which commonly involves imaging such as magnetic resonance imaging (MRI) and positron emission tomography (PET). Recently, to overcome limitations of each separate modality, PET and MRI were combined into a more efficient and accurate procedure for functional evaluation of imaging agent uptake with high resolution. However, this new technique also requires new contrast agents enabling the dual-modality assessment. To date, numerous nanoparticles have been researched but many require chelators for conjugation of radioisotopes to the nanoparticle surface. This raises concerns of radiolabeling stability and diagnostic accuracy. To address these issues, our project aimed at developing new PET/MR dual-modality nanoparticles by doping MRI contrast agents such as iron oxide (IO) and gadolinium oxide (GdO) with positron-emitter 64Cu. We first focused on the synthesis of nanoparticles through one-step reduction, copper doping efficiency, size and shape uniformity, contrast magnitude, structural stability, and surface modification. We then successfully incorporated 64Cu into IO with ~30% incorporation of total radioactivity and achieved high specific activity for sensitive PET detection. Further, phantom studies and in vivo pharmacokinetic evaluations suggested potential applications of this particle for PET/MR. We will continue the optimization for further *in vivo* animal PET/MRI studies.

Research in a New Diagnostic Tool for Light Chain Amyloidosis

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Systemic Light Chain Amyloidosis (AL Amyloidosis) is a rare disease in which the over proliferation of a plasma B cell leads to an excess release of immunoglobulin light chain (LC) protein in the blood stream. These LC proteins deposit as amyloid aggregates in various organs, mainly the heart and kidney. The diagnosis of LC deposition is challenging. Our goal was to evaluate an amyloid-specific probe molecule coupled to gold nanoparticles as a diagnostic tool for AL Amyloidosis. First, in vitro amyloid fibril formation was optimized in order to rapidly create fibrils. Salt concentration, shaking conditions, and temperature were varied in aggregation assays, and the aggregation kinetics were monitored using the amyloid specific dye Thioflavin T (ThT). We found conditions which generated LC aggregates with fibrillar structures identified by atomic force microscopy (AFM) within a week. The affinity of the coated nanoparticles was then analyzed using transmission electron microscopy (TEM).

Infiltration, Imidization, and Cross-Linking of Polyimides in Molecular-Scale Confinement

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Hybrid nanocomposite materials with a polymeric phase have novel properties—including exceptional toughness, strength, and low density—that are desirable for a variety of applications, including high-performance aerospace materials. Previous studies have shown that when the polymer within the hybrid material is confined to molecular-scale dimensions, nanocomposite properties are dramatically altered. In this work, we studied the effect of molecular-scale confinement on the synthesis and toughness of polyimide in a nanoporous matrix. In particular, we found that confinement in a nanoporous matrix significantly affected the behavior of the polyimide during synthesis of the nanocomposite material, including the infiltration of the polyimide into the pores, the ring-closing imidization reaction, and cross-linking between polyimide chains. We optimized the properties of the hybrid material by varying the processing time and temperature. The extent of polymer infiltration was monitored via depth profiling x-ray photoelectron spectroscopy. Ring-closing and cross-linking of the polymer were verified by Fourier transform infrared spectroscopy. Finally, by using double cantilever beam specimens to measure the cohesive fracture energy, we assessed the mechanical properties of the hybrid material. This work led to a better understanding of the effect of nanometer-scale confinement on polymer reactivity and mobility.

Optical Characterization of AlInAsSb Digital Alloy Films

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AlInAsSb shows promising application as a photodetector material throughout the near- to mid-infrared. The band gap of AlInAsSb can be widely tuned by adjusting the constituent element concentrations, while maintaining lattice matching to the substrate. Unfortunately, the fabrication of arbitrary alloys of AlInAsSb is hampered by a large miscibility gap. Using molecular beam epitaxy and a growth technique called digital alloying, AlInAsSb can be grown by alternating layers of III-V binary alloys of the constituent elements. Using this method, films were grown that reproduce the macroscopic optical properties of the bulk alloy. Here, we report on the emission and absorption characteristics of these digital alloys. Emission spectra were measured using photoluminescence spectroscopy at both 77 K and 300 K to determine bandgaps. Transmittance and reflectance data of these samples were measured using Fourier transform infrared spectroscopy. Due to the absorbance of the GaSb substrate, absorption features of wide-bandgap AlInAsSb alloys are obscured. To mitigate this, the spectra were also taken after thinning the substrate to ~150 µm. Absorption characteristics were extracted from the measurements using transfer matrix methods and numerical fitting. From these data, optical parameters of the films such as absorption coefficients and refractive indices were obtained.

Advanced Dielectrics for Microelectronics: Chemically Amplified, Low-k Materials

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Shrinking of the microelectronics package requires advanced low dielectric constant (low-κ) materials. Organic polymers offer more environmentally friendly and moldable than inorganic materials for microelectronic packages. In organic polymers, photo-definable dielectrics can be directly patterned by photolithographic means. Lithographically printed dielectrics do not require the use of photoresist or additional pattern transfer steps, which can be costly and expose the device to aggressive wet or dry etch process steps. Some organic polymers can be catalytically depolymerized by a small light stimulus. The catalytic phenomenon is called chemical amplification, and the polymers which depolymerize completely are called self-immolative polymers. Photo-definable, self-immolative polymers are depolymerized and become monomers by a light stimulus. Here, if vapor pressure of the monomer is high, the exposed material can evaporate and disappear completely. Traditional developing steps can be skipped because only light exposure and dry developing are needed. Conventional photo-definable self-immolative polymers have inherent problems, such as low mechanical strength and low vapor pressure of the monomer. Low mechanical strength makes them difficult to use as an interlayer insulating film, and low vapor pressure increases dry develop time. In this research, polymers that have high mechanical strength and higher vapor pressure are being synthesized. In this presentation, the preparation method of the polymer is discussed.

Ultrathin, Smooth, and Stable Doped Silver Films

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Silver's low resistivity, high conductivity, and low loss in the visible and near-infrared (NIR) regions makes it perfect for many optoelectronic applications. However, pure silver deposited on a dielectric substrate is unstable, rough, and requires a thick layer to form a continuous film. Al-doped Ag has been shown to circumvent these issues and provide an ultrathin and low loss film with subnanometer roughness. This makes Al-doped Ag a viable alternative to indium tin oxide (ITO) as a flexible transparent conductor. With the benefits of Al-doped Ag known, the purpose of this project was to co-sputter other metals with Ag and observe the results. The resistivity, conductivity, roughness, and optical loss of these different co-sputtered films were measured and a comparison study was performed to compare their properties to that of Al-doped Ag.

Optimizing Contact Resistance to MoS_2 for Improved Device Performance

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In recent years, much attention has been directed toward two-dimensional materials given their possible applications in next-generation Nano electronic devices. Graphene, the most widely studied two-dimensional material, has enjoyed major success due to its attractive electronic, thermal, and optical properties. However, graphene lacks a band gap which renders it unviable for use as a semiconductor in transistor devices. As a van der Waals material, MoS_2 is similar in structure to graphene with the exception that it has a band gap ranging from approximately 1.9 eV at monolayer thickness to 1.2 eV in bulk. As such, transistor devices have been fabricated using MoS_2, but major issues have arisen, including high contact resistance which have stifled device performance. In this paper, we examine the contact resistances between 1-2 nm Mo sulfurized (MoS_2) films and various metals including Au, Ti, Ni, Nb, and Mo using the two-terminal transmission line method. We also investigate the effect of annealing processes on decreasing contact and sheet resistances.

Aluminum-Induced Crystallization of Silicon Thin Films on Flexible Glass Substrates

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Highly-oriented silicon films on flexible substrates are attractive for production of thin-film electronic and energy applications. Ultra-thin flexible glasses are of special interest for substrate use because they offer flexibility as well as higher thermal stability than polymers at high temperatures. Thus, the goal of this project was to investigate the growth of Si films on 50-µm-thick flexible glasses, using aluminum-induced crystallization (AIC) process. AIC lowers the Si crystallization temperature to temperatures below softening temperatures of the glasses; furthermore, it produces Si films with large grains and preferential orientation. 30-nm-thick and 100-nm-thick large-grain polycrystalline Si thin films were successfully grown on 50-µm-thick flexible glass substrates. 30-nm films demonstrated larger grain size but higher resistance than 100-nm films. Mechanical flexibility was tested by bending the samples around a tube of radius 5.75 cm, close to the maximum curvature radius of the glass substrate (~4.5 cm). Bending caused the substrates to fracture but did not produce any cracks or delamination in the films themselves; bending also did not change the films' resistance. These results suggested high flexibility of the Si films. In comparison, bare glasses (with no films) did not fracture, suggesting the Si films added stress to the glass substrates.

Enhanced Mobility in a SiO_2 Capped 2DEG at $SrTiO_3$ (100) Surface

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Two-dimensional electron gases (2DEGs) at oxide surfaces and interfaces have attracted much attention due to their fascinating exotic properties such as superconductivity, large magneto-resistance, and ferromagnetism. $SrTiO_3$ (STO) based 2DEGs are a typical example. These include 2DEGs at the interface of $LaAlO_3$/STO heterostructures and on STO surfaces. With the high mobility and extremely high dielectric constant at the ground state, these 2DEGs are promising in developing next generation all-oxide devices including field effect transistors and spintronic devices. In this study we have created 2DEGs at STO (100) surfaces by Ar ion irradiation. We found that a SiO_2 capping layer on the 2DEG surfaces significantly decreased surface resistance while no effect was observed for other oxide capping layer tests (MgO, Al_2O_3, and STO). Specifically the electron mobility of the SiO_2 capped channel had an eight-fold increase relative to uncapped 2DEG at 1.8 K. The bare channel had a resistance ratio (R300 K/R1.8 K) of 85 compared with the SiO_2 capped channel ratio of 625; this indicates better metallic behavior for capped channels. Our results open a path to create 2DEGs with high mobility in an effective and economic way.

Fabrication of Diamond Ultraviolet Light Emitting Diodes

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Ultraviolet light emitting diodes (UV LEDs) have been used in a variety of applications and as a result are becoming cheaper to fabricate. LED products have reached 12 watts at 914 amperes. Initial UV LEDs were fabricated with GaN films grown on sapphire substrates. The main disadvantage of this fabrication technology is the difficulty in growing high quality GaN films on sapphire because of the large lattice mismatch. Diamond has a wide energy band gap of 5.47 eV; which makes it attractive for opto-electrical applications. Its high thermal conductivity makes it an excellent material for UV LED fabrication. In this work diamond UV LEDs were fabricated by growing high-quality diamond films on silicon and silicon carbide (SiC) substrates by hot filament chemical vapor deposition (HFCVD). Methane was used as the carbon source gas with solid source boron used as the p-type dopant and nitrogen used as the n-type dopant. Hall measurements confirmed a hole concentration of approximately $3\times10^{19}cm^{-3}$, a carrier mobility of 73 cm^2/V-sec, and a resistivity of $5\times10^{-3}\Omega$-cm.

Optimizing Hard Mask Etching for Quartz Nano-Devices

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Quartz, as an engineering material, has been well recognized for its superior mechanical properties in piezoelectric devices. Recently, quartz has also shown potential for use in nano-scale tunable optical filters. However, due to the lack of thin film platform technology for quartz, its use has been limited to micro-scale devices.

In this project, an angled-etching fabrication technique has been adopted to realize nano-scale quartz devices. In fabrication, evaporated or sputtered thin aluminum or titanium films are used as a hard mask. We worked to optimize dry etching of these masks to transfer a smooth sidewall to the final device. We experimented with various etch recipes and studied how temperature and the DC bias affect etch quality. By optimizing these two parameters, the final recipe yielded a cleaner etch by creating a more volatile environment in the chamber, preventing residues from settling on the substrate and creating a more anisotropic etch. Using facilities at Harvard University's Center for Nanoscale Systems, we etched and imaged samples to establish a trend regarding the effects changing pressure, temperature, and DC bias had on anisotropy and selectivity. Our biggest success with both aluminum and titanium etching has been with raising temperature and DC bias.

Minimizing Losses in TiO_2 Thin-Film Waveguides for Nanophotonic Applications

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Integrated optics is a rising field that aims to combine a variety of photonic functions onto a single chip platform. Attaining this goal necessitates refining the optical waveguide, a structure that allows for light to be captured and transmitted via total internal reflection. Planar thin-film waveguides, a popular version used in nanofabrication settings, are typically constructed by sandwiching a thin layer of high-index material between two lower index materials. This summer, I built and tested such devices by depositing amorphous titanium dioxide (180-200 nm) onto thermal oxide silicon wafers through the process of physical vapor deposition (PVD). The intention was to manipulate the temperature, power, and pressure parameters of the deposition procedure and examine the effects on film quality (as evaluated through loss measurements and surface roughness), index of refraction, and sputtering efficiency. Furthermore, conclusions derived from this experimentation were used to determine which of the factors produced the lowest loss films when tested with a prism coupler setup and a laser of wavelength 638 nm. Because loss effects from impurity and defect scattering vastly diminish the effectiveness of waveguides, this research is key to making integrated optics a competitive technology for information transmission and the electronics industries.

High-Efficiency Broadband Lippmann-Bragg Reflection Holograms

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Reflection holograms are written into a light-sensitive media using a source of coherent monochromatic light. The interference pattern between two interfering light waves causes polymerization of certain regions of the recording medium. Unreacted monomer diffuses into the regions that polymerized, creating a nonuniform refractive index across the media. This uniform fringe pattern that occurs, a reflection hologram, reflects light. Typically, reflection holograms are very wavelength selective. In order to broaden the region over which the reflection holograms are reflective, the fringe patterns must be non-uniformly stretched, or chirped. By introducing a monomer sponge next to the holographic media, monomer diffuses into the fringes and stretches the ones closest to the interface first, causing nonuniform swelling. We have found that reflection holograms, once chirping has begun, take 1 hour in order to reach their maximum FWHM bandwidth state. During the entire chirping process the peak wavelength location is steadily increasing. Concluding after 79 hours, the bandwidth decreased and reflectivity increased to near their original values as monomer equally diffused. At maximum FWHM bandwidth, reflectivity decreased by 230% and bandwidth increased by 200%. After 79 hours, holograms experienced a volumetric expansion of 11% coupled with a peak wavelength shift of 12%.

Fabrication of Bio-Inspired Photonic Structures for Antireflectivity in Cadmium Telluride Infrared Detectors

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Moth-eye structures are emerging as an anti-reflection surface capable of enhancing broadband transmission and functioning at off-normal incidence. As such, they provide an alternative to interference based thin-film coatings. The Gordon group is developing a procedure to produce moth-eye structures on cadmium telluride for infrared detection applications. Photoresist is spun onto a cadmium telluride wafer, which is then coated with colloidal silica nanoparticles by the Langmuir-Blodgett method to form a mask. A CHF_3/O_2 inductively coupled plasma etch is used to reduce the size of the nanoparticles, after which the photoresist is etched by O_2. This allows for a $CH_4/H_2/Ar$ etch of the cadmium telluride, followed by an additional O_2 clean and an acetone rinse to strip the mask. The result is a set of cadmium telluride columns, retaining the order of the colloidal mask. This has been shown to increase transmission through the interface between the air and cadmium telluride to above 90% over a range of wavelengths from 3 to 8 microns. The method for applying a moth-eye structure to cadmium telluride, along with its optical effects, will be presented.

In Fiber Flow Rate Sensors using Thermally Drawn Multi-Material Fluidic Channel Fibers

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In fiber flow sensors allows for easy integration, simplicity, and low power consumption for various micro-fluidic applications. The thermal reduction process allows for integration of many different materials into a fiber with uniform geometry over several kilometers. Thermally drawn multi material fibers with conductive polyethylene (CPE) fluidic channels were developed. In response to thermal gradients CPE film changes its resistivity. The initial resistivity of CPE was measured to be 0.35 Ωm before fabrication and 0.18 Ωm after being drawn into a fiber. Then the change in resistance in response to various flow rates were measured. The flow sensor can then accurately determine the flow rate based on the resistance measured. The channel fibers were found to have the highest sensitivity of 0.52 V/(uL/min) in the 0-40 µL/min range at bias current 1mA.

Fabrication of All-Aluminum p-Type Silicon Solar Cells

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In typical silicon photovoltaic solar cells, the front finger electrode is made of silver. Silver's cost and relative scarcity is a hindrance to the mass production and implementation of the silicon solar cell technology. A low-cost and abundant alternative to silver is needed before silicon photovoltaic systems are able to provide for a significant fraction of the world's energy needs. This project aims to adhere aluminum — a low-cost, abundant, and conductive material —via electroplating, to a conventional p-type silicon solar cell. The effect of post-deposition annealing temperature on the solar cell's parameters was investigated: increasing the annealing temperature has a deleterious effect on the device's performance parameters. The study's best solar cell has an efficiency of 12.4%. Further studies are needed to ascertain the causes of the device's poor performance.

Fabrication of Light Emitters and Photovoltaic Cells with GaAs Nanowires on Metal Substrates

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Complementary Metal Oxide Semiconductor (CMOS) technology is continually decreasing in size. Right now, the smallest device is the Micro-Mote, which is less than a half a centimeter. This small device can be implanted in people with diseases such as glaucoma, and it can monitor the intraocular pressure. Its power source is a solar cell on the very top layer. A smaller design has been proposed that will reduce the weight and increase the reliability. Instead of having a 3D cube with layers of chips stacked on top of each other with wire bonding between each layer, the device can be placed all on one layer. The problem is directly integrating LEDs and solar cells onto the processor. This can potentially be done with thin-film GaAs nanowires, which have been shown to make high efficiency light emitters and photovoltaic cells, and have the potential for integration on arbitrary substrates. However, nanowires have dangling bonds that can decrease the efficiency of light emitters and photovoltaic cells. To improve the efficiency of GaAs nanowires, deposition of parylene on GaAs nanowire arrays are studied in this work to provide both structural support and surface passivation.

Evaluation of TiO_2 as Carrier Selective Contact for High Efficiency Photovoltaic Applications

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The most efficient silicon solar cell today uses amorphous silicon (a-Si) to passivate the surface and selectively collect carriers from the crystalline silicon (c-Si). However, a-Si absorbs some of the light that the c-Si could turn into carriers. Current research is looking into a potential replacement for a-Si that has the same passivation properties and comparable selectivity but does not absorb usable light. We are investigating TiO_2 as a candidate to replace the a-Si layers in solar cells. With a band gap of 3.2 eV, TiO_2 is transparent to visible light and its band-structure theoretically should line up with c-Si's making it a good electron selective contact. Using thermal atomic layer deposition (ALD), we prepared TiO_2 films at different temperatures, evaluated their surface passivation properties as-deposited and after post-deposition treatment, and finally we assembled solar cells with TiO_2 replacing the n-type a-Si layer in a Heterojunction with Intrinsic Thin (HIT) layer structure. Our results suggest that the passivation quality of TiO_2 is not as good as a-Si, with minority carrier lifetimes of 100 µs, leading to low open-circuit values of 560 mV in the final cells. We show that TiO_2 is capable of selective electron extraction, but high efficiency cells will require an additional surface passivation layer and further process optimization.

Graphene/III-V Electro-Optic Hybrid Devices

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Intracavity loss modulation is a promising method for broadband noise suppression in a modelocked laser. However, pure loss modulation with bandwidth beyond megahertz is rarely achieved with traditional electro-optic materials due intrinsic resonances, amplitude and phase coupling or signal propagation delays. Graphene, arising as an unconventional two-dimensional material, exhibits an interband absorption of 2.3% from visible to infrared wavelengths, which is controllable by an external electric field. This exciting property has been utilized recently and has led to unprecedented noise level in compact fiber-based modelocked lasers. In this work, we integrate a graphene modulator on a semiconductor-based saturable absorber mirror, which serves as a device for initialization and stabilization of modelocking. This hybrid device exhibits modulation bandwidth beyond 1 MHz, which is sufficient for most noise-suppression applications. The realization of this hybrid device is based on the design and improvement of the top silicon-doped GaAs layer of the saturable absorber mirror, functioning as a transparent electrode. Various annealing conditions of the top layer and the resulting sheet resistance, carrier lifetime, and optical absorption changes are presented and discussed, along with the modulation performance of the graphene modulator.

Graphene Junction Field Effect Transistors on a Silicon Carbide Substrate

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Transistors are extensively used in mainstream electronic devices and are primarily fabricated on a silicon substrate. As nanotechnology has advanced, we have been able to produce increasingly smaller transistors; however, quantum mechanics predicts that this continual smaller scaling on silicon will soon end and we will need to find a replacement transistor material to progress further. We are investigating silicon carbide as a potential replacement due to its desirable properties and the compatibility with existing fabrication methods and with graphene growth processes. The top graphene layer can be created either through a thermal decomposition reaction directly on the silicon carbide surface (epitaxially grown), or it can be grown on a metal substrate and then transferred onto the silicon carbide. We intend to explore the viability of both types of graphene as laterally-conducting channel materials for junction field effect transistors (JFETs). We chose JFETs over the more widely-used metal-oxide-semiconductor field effect transistors (MOSFETs) due to the direct contact between the graphene and the silicon carbide without an insulating oxide layer in between, which has not previously been studied. In theory, our novel device will allow for greater current control since both the substrate doping and the applied voltage can be tuned.

High Aspect Ratio Dry Etching of Gallium Nitride

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Light emitting diodes (LEDs) have allowed for the creation of more efficient lights and longer lasting devices. These devices are formed by overlaying a substrate with doped layers of material through epitaxial growth. However, substrates are usually foreign materials and have different crystal structures than their epilayer; because of this, epitaxy becomes non ideal and overall LED performance suffers. The focus of this project is to construct dry etched Gallium Nitride (GaN) pillars that can be generated on top of foreign substrates to improve epitaxial growth and create LEDs that offer more light power per wafer area. By using inductively coupled plasma (ICP) etching and changing etch plasma parameters, GaN pillars were constructed. These pillars were then analyzed by measuring their radius of curvature, characterizing its profile, and evaluating the quality of the fabricated pillars. As GaN etch depth increased, radius of curvature decreased by the GaN pillars. This, in turn, relaxed the wafer and increased the potential for higher quality epitaxial growth. However, due to non-uniform and etched away pillars created through this processing, there is still room for more research to generate these types of pillars on foreign substrates for LED and electronic device use.

Electrostatic Gating of MBE-Grown $NdTiO_3$ Thin Films

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With the emergence of ionic gel gating in an electric double-layer transistor (EDLT), materials that could not be easily chemically doped, or had significant structural changes upon being doped, can now be examined. $NdTiO_3$ (NTO) is a Mott-Hubbard antiferromagnetic insulator, with the insulating state being sensitive to doping and chemical distortions. This experiment explores the use of ionic gel gating in order to investigate the insulator-to-metal transition in NTO thin films using electrostatic doping. Single crystalline, epitaxial NTO films were grown onto an insulating substrate using a hybrid molecular beam epitaxy technique. The device was patterned using two shadow masks, one for etching with ion milling and the other to deposit metal contacts with sputtering. The ion gel, 1-ethyl-3-methylimidazolium-bis (trifluoromethylsulfonyl) imide (EMI-TFSI), was placed on top of the patterned NTO films and electronic measurements were taken in a Physical Property Measurement System (PPMS). The influence of ionic gel on the electronic transport of NTO films was determined by performing measurements before and after the placement of ionic gel. Voltage-dependent leakage current through the ionic gel was established, which allowed for calculation of injected charge. Temperature-dependent resistivity measurements were performed for each gate bias.

Image Reconstruction through Scattering Media Using a Single-Pixel Camera

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Improved techniques to efficiently image (at optical wavelengths) objects embedded in or obscured by highly scattering media are desirable due to the large number of potential applications, most notably in the arena of biomedical imaging. In this experiment, we tested the performance of an image reconstruction technique utilizing Hadamard analysis and single-pixel photodetection of both forward and backscattered light. Resolution targets were fabricated and obscured by scattering media, and subsequently illuminated with structured light patterns projected by a digital micromirror device. Outgoing scattered light was collected and focused onto a photodiode, and the resulting signal analyzed in order to reconstruct an image. We tested imaging of reflective targets illuminated with incoherent white light, and are currently doing the same with fluorescent targets illuminated by a supercontinuum laser source tuned to the proper excitation frequency.

Zinc Oxide Deposition Methods for Opto-Electronic Applications

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Due to the increasing cost of indium tin oxide, new materials such as zinc oxide (ZnO) are being explored for use in the transparent conductive oxide (TCO) layer of opto-electronic devices such as LEDs. The purpose of this layer is to spread current over a wide area while also allowing light to pass through. This project investigates atomic layer deposition (ALD) and hydrothermal deposition to grow ZnO films for the (TCO) layer LEDs. First, a seed layer of zinc oxide is deposited via ALD; the thickness of this layer ranges from 4 to 16 nanometers depending on the number of ALD cycles chosen. This layer is then annealed to improve the crystal quality and increase conductivity by minimizing defects and increasing the mobility of carriers. The second, main layer of zinc oxide is grown using hydrothermal deposition and then annealed. This layer is doped to increase the number of carriers, and its thickness ranges from 1 to 3 micrometers. Hall effect, transmission, and sheet resistance measurements are taken to quantify the performance of the ZnO films, and the goal of this project is to optimize the electrical and optical properties by adjusting the conditions in which the ZnO is grown.

Nanoscale Light Emitting Diodes with Tunable Emission Colors

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InGaN nanodisks in GaN nanopillars have been investigated extensively and have shown advantages over a planar structure. They have been applied as the active region in light emitting diodes (LED) for multiple color pixels. This device is fabricated using a top-down approach. During the etchback of the Spin-on-Glass (SOG), using $SF_6/C_4F_8/Ar$ gas, the tip of the p-type GaN is exposed using inductively coupled plasma (ICP). As a consequence, the electrical properties of the GaN deteriorate, e.g. the turn-on voltage and contact resistance increase. Therefore, a recovery treatment is required to restore the damage. We report on damage recovery by means of wet chemical treatments and rapid thermal annealing (RTA) on p-GaN samples initially without nanopillars. Using hydrogen chloride, potassium hydroxide (KOH), and molten KOH, the wet chemical treatment can etch the damaged layer. RTA provides thermal energy which results in dopant reactivation and repairs surface damage from ion bombardment. We measured the contact resistance using rectangular and circular transmission line methods to determine which treatment can be used to optimize the device. The results demonstrate that for our sample KOH shows the most improvement in resistance. Finally, these results are used in the fabrication of the InGaN/GaN LED.

Bandwidth Expansion for Lippmann-Bragg Holographic Photopolymers

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Constructive and destructive interference of monochromatic light waves from a split laser source creates a pattern of high and low light intensity areas that are recorded into a photo-sensitive material, creating a reflection hologram. A reflection hologram that has a high reflectance over a broad range of wavelengths is desirable for many applications. Thicker holograms, which have a higher reflectance, also have a very narrow bandwidth, thus obtaining a higher bandwidth typically requires layering. A post-processing method called "chirping" is used to expand the bandwidth of these reflection holograms. By diffusing mobile monomer into a recorded hologram, we are able to swell the material and create a distribution of fringe spacing that increases the bandwidth.

Starting with a bandwidth of 2.5nm with a maximum reflectance of 2.25% occurring at 457.0nm, after one hour of chirping the bandwidth expanded to 9.7nm while the maximum reflectance dropped to 0.60% and shifted to 466.6nm. This trend was observed until 5 hours of chirping at which point the bandwidth narrowed and the maximum reflectance went back up. The change in mass of the hologram was 8.05% which matches closely with the 8.35% swelling observed from the shift in maximum reflectance from 457.0nm to 495.2nm.

Design and Analysis of Nanoscale Resonators to be Integrated with Monolayer Heterostructures

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Unprecedented material compatibility and unusual optoelectronic properties of single-atom thick monolayer materials have generated strong interest in building devices with them in the recent years. The full potential of such materials can be realized if one stacks such materials, and integrates them with nano-scale resonators to increase the light-matter interaction. However, for this process to be effective with such monolayer heterostructures, specifically the interlayer excitons observed in previous results, the resonator must be able to support a transverse magnetic (TM) mode in order to possess a strong electric field in the direction perpendicular to the monolayer material stack, or the surface of the cavity. This requirement is fundamentally different from resonators designed for single monolayers, where light only with polarization parallel to the surface is effective. In this report, we present a design methodology to build photonic crystal resonators to support TM modes. Previous results used a much thicker geometry for the resonator, which poses a problem for fabrication due to long etching time. Using those as starting designs, using finite-difference-time-domain simulation, we design a cavity with only 250nm thickness exhibiting TM resonances at 900-950nm range, the typical wavelength range for the WSe_2-$MoSe_2$ interlayer excitons.

Optical Resonant Frequency Detection System for Mass-Sensing MEMS Resonators

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Photonic crystal nanostructures are essential in combining two important technologies: optical tweezers and MEMS resonators to allow effective trapping and enhanced-precision measurements of cell mass. MEMS resonators measures the cell mass by detecting the resonant frequency change of the resonant beam. Photonic crystal optical tweezers are applied to improve the mass sensing capability of MEMS resonators by fixing the cell position with low light intensity. This enables the investigation of a cell's biophysical properties. A detection system consists of a split photodiode and detection circuitry was built to measure the resonant frequency of a micro-machined resonator. A laser beam incidents onto the vibrating resonator and produces an optical deflection signal (ideally resembling a sinusoidal wave) upon hitting the split photodiode. By using the circuit design software, Multisim, an effective circuit schematic was created that would convert the output current of both photodiodes to an adequate voltage to effectively view and measure the resonant frequency. During this process, simulations were conducted, so that the behavior of the circuit could be predicted, before actual assembly. With the usage of an Arduino microcontroller and programming software, the frequency of the circuit's sinusoidal wave could then be measured.

Microfabrication and Testing of Directional Piezoelectric Microphones Using Aluminum Nitride

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This project focuses on the fabrication and characterization of piezoelectric microphones with out-of-plane directivity. These devices use a 1.2-µm-thick aluminum nitride (AlN) thin film as the piezoelectric transduction material in place of lead zirconate titanate (PZT), utilized in earlier prototypes. Previous devices were highly resonant at 2.6 kHz, distorting recorded sound. One of the main focuses of this project is to provide an even response within the audible frequency range. AlN shows a lower dielectric loss (tanδ) than PZT (i.e., a smaller leakage resistance and thus achieves a higher signal-to-noise ratio.) In addition, AlN opens the possibility for CMOS integration in system-on-a-chip designs. Lastly, AlN does not require a poling process, as the internal polarization of AlN is defined by crystalline orientation (i.e, c-axis) achieved in this study via DC reactive sputtering. Fabricated prototypes have a diaphragm made of 10-µm-thick epitaxial Si, supported by a thin silicon beam on which the piezoelectric thin film and electrodes are deposited. In preliminary testing, application of an AC voltage signal across the device electrodes yielded motion of the diaphragm detected with a Laser Doppler Vibrometer, showing evidence of a functional piezoelectric AlN film and frequency response which matched expectations.

Optimum Sputtering Conditions for *in situ* Crystallization of PZT Thin Films on Flexible Metal Foil

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The applications of piezoelectric microelectromechanical systems based on $Pb(ZrxTi_{1-x})O_3$, or PZT, thin films could be expanded by the use of flexible metal foil substrates. Strongly oriented {001} PZT thin films showing high piezoelectric response with a low dielectric constant have been grown on flexible Ni foil substrates by chemical solution deposition (CSD), which improved the figure of merit for piezoelectric energy harvesters. The goal of this research was to develop a process for growing comparable films by high temperature sputtering, thereby simplifying the deposition process for obtaining desired film thickness and allowing for in-situ crystallization. $Pt/Ti/SiO_2/Si$ substrates, and those with a PZT seed layer, were used because Ni foil requires additional processing. Changing the pressure altered the lead content of the film, which is vital for obtaining pure perovskite without secondary pyrochlore phase. Control of oxygen flow during sputtering also modifies the lead content of the deposited film. Conditions of 670°C, 12 mTorr, with no oxygen flow yielded the best results, but pyrochlore was still present. PZT will next be sputtered under lower pressures with oxygen flow. Once optimal conditions are found, oriented PZT thin films will be deposited on Ni foil substrates.

Design and Fabrication of Graphene on Nitride Accelerometer

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Piezoresistive materials change resistance in response to stress. In a piezoresistive accelerometer, displacement of a proof mass causes strain on the proof mass support, which consists of a piezoreistsive element, translating to measurable changes in resistance. The focus of this project is the fabrication of graphene piezoresistors on silicon-nitride accelerometers in order to test noise performance, frequency response, and piezoresistive gauge factor for graphene. Graphene is atomically thin, allowing for scalability to extremely small accelerometers for potential implementation in large arrays of sensors. In general, an atomically thin mechanical transduction element can provide new pathways to realizing nanoscale arrays of nano-electro-mechanical systems (NEMS). Fabrication of the devices took place at CNF. Low stress nitride was deposited on a wafer, followed by deep reactive ion etching to etch high aspect ratio trenches from the backside and release a bulk silicon proof mass. The nitride layer connecting the proof mass to the substrate serves as the spring for out-of-plane acceleration measurements using the device. Finally, nickel was deposited for metallization contacts via a lift-off process, and piezoresistors made of transferred graphene patterned using oxygen plasma. Devices were successfully fabricated and tested for frequency response and noise performance.

Determining the Spin Hall Angle of Gadolinium

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The spin Hall effect is observed when electrons from a charge current are deflected based on their spin orientation, causing an accumulation of spins on the boundaries of a material. The spins can then exert a torque on an adjacent ferromagnetic material, potentially manipulating the orientation of the magnetization. It has been found that manipulating nanomagnets through spin transfer torques is much more practical than using a magnetic field. Therefore, spin transfer torques present advantages in non-volatile magnetic memory applications. The effectiveness of the spin Hall effect in a given material is described by the spin Hall angle, a ratio of the generated spin current to the applied charge current. This research focuses on determining spin Hall angle of Gadolinium. Material stacks consisting of 10 nm of Gadolinium and 5 to 10 nm of a ferromagnetic material were deposited on a sapphire wafer through sputter deposition. Hall bars were patterned through photolithography and ion milling procedures and Platinum contacts were then deposited through photolithography and sputter deposition. Various electrical measurements were performed on these devices to determine the spin Hall angle.

Fundamental Studies of the Synthesis of Graphene Using the Plasma Enhanced Chemical Vapor Deposition Process

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Graphene is a two-dimensional form of crystalline carbon, which has a linear band structure and the highest known carrier mobility of any material. Thus, many researchers have utilized graphene in high-performance devices to realize practical applications like high mobility transistors, THz antennas and transparent electrodes. However, these innovative devices require the ability to synthesize uniform, high quality, and large-area graphene layers. Until now, the growth methods for high quality graphene were primarily focused on thermal decomposition of silicon carbide (epitaxial growth of graphene) and chemical vapor deposition onto transition metals. However, these process need to be performed at high temperature, exceeding 1000°C, which is incompatible with conventional device fabrication processes.

In this study, a plasma enhanced chemical vapor deposition (PECVD) process was investigated in order to attempt the low temperature growth of graphene on copper foils, maintaining the requirements of large area and high quality synthesis. Graphene samples were grown on thin copper foils at temperatures from 200-500°C in a plasma of H_2, N_2 and CH_4. Plasma power ranged from 10 to 100W at a frequency of 15kHz. Raman spectroscopy was used to analyze the resulting films for graphene content and quality.

The Optimization of Thin Film Molybdenum Disulfide Synthesis

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Molybdenum disulfide (MoS_2) belongs to the family of materials known as layered transition metal dichalcogenides (TMDCs), which offer unique mechanical, electronic, and optical properties that show promise for the next generation of nanoelectronics. The development of a method to grow uniform, high-quality MoS_2 at wafer-scale is necessary for its integration into modern electronics. Uniformly thick, wafer-scale MoS_2 films have been grown by sulfurization of thin molybdenum films, though the polycrystalline nature of the resulting films limits their electrical performance. Small crystal grain sizes have a detrimental effect on the performance of devices due to scattering effects that limit carrier mobility and reduce on-off ratios. The focus of this project was to investigate high temperature annealing of MoS_2 films in order to increase grain size. MoS_2 films were grown by e-beam evaporating molybdenum films onto thermally oxidized silicon substrates, followed by annealing in a sulfur-rich environment at temperatures up to 1000°C. Sulfur evaporation from the MoS2 film, sulfur contamination of the SiO_2 substrate, and sulfur droplet formation limited the possible annealing conditions, which were optimized for the electrical and structural properties of the MoS_2 film. The MoS_2 films were characterized using scanning electron microscopy, Raman spectroscopy, and x-ray photoelectron spectroscopy.

Improvement of Sodium-Ion Batteries Using Solution-Grown Germanium Nanowire Anodes

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The use of solution-grown germanium nanowires (GeNWs) as anodes in sodium-ion batteries (NIBs) was studied. GeNWs are promising candidates for NIB anodes because Ge alloys with sodium at room temperature with a relatively high theoretical capacity (NaGe, 369 mAh/g). The nanowires can tolerate the volume changes that occur during cycling without degradation and their high surface area-to-volume ratio yields suitable charge/discharge kinetics in the battery. GeNWs were produced using a supercritical-fluid-liquid-solid (SFLS) growth process and then activated with initial lithiation/delithiation cycles (at a rate of 1C). SEM images revealed that a solid electrolyte interphase (SEI) layer formed during this treatment and increased in thickness with each additional cycle. Sodiation was tested at a charging rate of C/10. Without polishing the positive sodium electrode, the highest charge capacity of the Li-activated GeNWs was 150 mAh/g NW. Polishing the sodium foil counter electrode significantly improved the charge capacity to 350 mAh/g NW due to the removal of an oxide layer. The Coulombic efficiency of the half-cell, however, was still low (40%). To improve reversibility, the effect of nanowire electrode film thickness was studied (thickness: 0.7-1.3 µm), but there was no significant change in performance in this thickness range.

Surface Adsorption and Enzymatic Hydrolysis of Polyphosphates: Implications for Understanding Phosphorus Cycling

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Phosphorus (P) is a key nutrient yet often limited in aquatic environments. Among various species of phosphorus, polyphosphate constitutes a significant species related to biological activities and is produced by almost all organisms. Polyphosphates are long chain molecules of phosphate with varied chain lengths (e.g., P units). Yet little is known of the cycling and transport of it within natural environments. This project characterized the mineral adsorption, enzymatic hydrolysis, and mineralization of polyphosphates under environmentally relevant conditions. Adsorption of polyphosphate onto common iron and aluminum oxides was studied with batch adsorption experiments. Polyphosphate hydrolysis catalyzed by alkaline phosphatase was studied by monitoring orthophosphate (orthoP) formation using UV-Vis spectroscopy. It was observed that polyphosphate can be degraded through enzyme-catalyzed hydrolysis with the rate and extent dependent on chain length. In the presence of calcium (Ca), precipitation of Ca-orthoP solid phase(s) was observed and characterized by dynamic light scattering, scanning electron microscopy with energy dispersive spectroscopy (SEM-EDX), and Fourier transformed infrared spectroscopy (FT-IR). FT-IR spectra and elemental analysis from EDX suggested the precipitate to be a non-apatite phase, likely a type of amorphous Ca-orthoP.

Vanishing Programmable Resources: Design, Materials, and Characterization

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Printed wiring boards (PWBs) act as the mechanical structure supporting the electronic connections between the different functional components in microelectronic devices. Stable materials are generally desired so that long mission life can be achieved, however, there is growing interest in self-decomposing materials because of environmental concerns. This has prompted the development of PWBs that can be triggered to disappear after a time-independent, fully-functional life span. For this project, an optically-triggered disappearance mechanism was explored. UV-sensitive polymers were characterized using methods such as dynamic mechanical analysis, four-point probe analysis, nanoindentation, and photo-speed. These same methods were used to analyze composite films that contained either copper or fiberglass in addition to the polymers. The addition of copper provides the conductive portion of the PWB, and the fiberglass was used to help with the mechanical stability of the core, non-conductive portion. Two polymers were tested. Polymers 1 and 2 with no additive had a Young's modulus of 4.2 GPa and 55 MPa, respectively. A conductive film with 75 vol% 3 µm dendritic copper was made and had a conductivity of $4.5 \times 10^3\ \Omega^{-1}m^{-1}$. This work shows that an electronically functional PWB can be created with materials that are capable of triggered disappearance.

Simulation and Nanofabrication for Tip-Enhanced Raman Spectroscopy

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Tip-Enhanced Raman Spectroscopy (TERS) is a fast-growing branch of spectroscopy using inelastic light scattering to characterize and analyze materials with nanoscale spatial resolution. By placing a metal coated tip or probe in close proximity to a sample, incident laser radiation creates a surface plasmon on the surface of the probe, which generates a high intensity localized electric field that produces greater signal strength when compared to conventional Raman spectroscopy as well as achieving resolutions below the diffraction limit. The goals of this project are to (1) realistically model and simulate the TERS set-up for gold-coated AFM tips, (2) perform modified TERS experiments on molecules deposited on an Au film and Au nanotriangle (AuNT) substrates. Much effort was placed into creating realistic tip models and simulations which are lacking in the literature. This was achieved using Rsoft's DiffractMod software package and agreed with both theoretical intuition and experimental results. TERS Experiments were then performed on molecules of Azobenzene on both an Au film and AuNTs.

Electric Field-Directed Assembly of Nanowires on Patterned Electrodes

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Many researchers have shown that the assembly of nanowires could lead to future electronic and optical devices. My project focused on assembly of gold nanowires in an alternating current (AC) electric field between parallel electrodes. Assembling nanowires requires a great deal of control, which is why the electric field system is ideal. The bottom electrode was lithographically fabricated and contained organized micro- patterned pillars made from photoresist on top of a layer of titanium and gold. The top electrode was an indium tin oxide (ITO) coated glass coverslip. Since this electrode was transparent, the assembly could be monitored in real time. Pillars were 3 µm tall and 3-20 µm in diameter, with spacing varying from 10-55 µm. These pillars acted as nucleation sites for the assemblies. Electric field-induced dipoles align the nanowires parallel to the field lines between the two electrodes. By varying different parameters, such as voltage and frequency, specific and controlled placement of the nanowires was possible and can be varied in real time. The assemblies can be reversed and replicated by switching the field on and off. This technique can be used to achieve specific assembled structures for electronic applications.

Fabrication of Test Samples for Calibration and Testing in Three-Dimensional Super Resolution Microscopy

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Three-dimensional super resolution microscopy allows researchers to circumvent Abbe's Diffraction Limit while capturing images of biological specimens with immense detail (one order of magnitude better than the diffraction limit). Due to the increasing resolution and ability to examine nanoscopic features, knowledge of our measurement accuracy and precision is essential. The focus of this project is to create test samples with known dimensions that emulate biological samples in order to calibrate and test 3D super resolution microscopy systems. A Focused Ion Beam transferred nanoscopic patterns into thin layers of opaque chrome deposited on a glass substrate. These test samples allow us to evaluate the precision of a given instrument, as well as investigate the extent of optical aberrations across the field of view. Currently, an additional design is being fabricated to test the resolution limit of point sources in close proximity due to the ambiguity caused by overlapping Point Spread Functions.

A Suspended Heater Wire for Low Power Gas Sensing Using the 3-Omega Technique

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The 3-Omega measurement technique is applied to a suspended heater wire for the purpose of low power gas sensing. The gas sensor is fabricated by uniformly sputtering a conducting material onto the surface of an insulating core. For this study, gold, copper and platinum were sputtered uniformly on a fiberglass core. Uniform coating of the metal was obtained by means of a spinning lathe that was designed to work with the sputtering equipment. SEM images of the cross section of the fiber validated the uniformity of the coating. A custom 3-Omega circuit controls the AC heating current and measures the 3-Omega voltage. The amplitude and phase lag, and the in-phase and out-of-phase components of the 3-Omega signal are presented for each case and are related directly to gas concentrations. The phase lag signal has the advantage of determining the gas concentration without the need for individual sensor calibration. In addition, the sensor has the advantages of low power consumption compared to commercially available sensors, and ease of fabrication.

Nanofabrication and Characterization of Quasi-Crystal Metasurfaces using Shadow-Sphere Lithography

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Aperiodic and quasiperiodic metasurfaces have great potential for application to ultrasensitive biosensing, but their development has been slowed by difficulties in i) fabricating them over large areas and ii) simulating their optical properties computationally. To address these challenges in nanophotonics, the Whitesides lab has recently developed a method for high-throughput fabrication and screening of quasicrystalline metasurfaces using template-directed self-assembly combined with Shadow-Sphere Lithography (SSL). In this project, we focused on optimization of the self-assembly process and on the quasicrystal fabrication and characterization. Using an etched silicon template, silica microspheres were assembled in a Penrose Tiling pattern and transferred to glass. To fabricate quasicrystals, we deposited gold at different angles onto the patterned spheres. On the surface of the glass, the angles of deposition created "shadows," regions where gold had not been deposited. Once the spheres were removed, these complex shadow patterns were left behind with features as small as 20 nm. We fabricated arrays that included 78 different quasicrystals, with various sizes and patterns, on a single 3.5 x 7 mm surface. Being able to produce hundreds of quasicrystals in parallel allowed for these crystals to be fabricated and characterized within hours—much faster than they could be simulated. The speed, variety of allowable patterns and sizes, and reproducibility of the fabrication process permit for high-throughput screening of the quasicrystals. Characterization of these quasicrystals using FTIR spectroscopy has revealed sharp peaks in reflectance around 1000 nm. These sharp peaks combined with high-throughput screening allowing for potential use in biosensing.

Diblock Copolymers for Diamond Patterning and Applications

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Nitrogen-vacancy (NV-) centers have been recently forecasted as possible quantum bits – the fundamental unit of quantum information. Their properties include long spin lifetimes and the ability to store quantum information and transmit it in the form of light [1]. However, interaction with their environment leads to decoherence in the presence of nearby nitrogen spins. The key to enhance the NV- center is to reduce its interaction with their environment by keeping them separated. The goal of this project is to create a mask that will assist in the fabrication of diamond nanopillars (DNP). Here, we present various methods that allows for control over the size and location of the DNPs. A Hot Filament Chemical Vapor Deposition (HFCVD) reactor is used to grow polycrystalline diamond on silicon wafers. The diblock copolymer Poly(styrene)-$_{block}$-(2-vinyl pyridine) (PS-$_{b}$-P2VP) is used to create a mask that directs the location and size of the DNPs. Reactive Ion Etching (RIE) is then used to transfer the patterns from the mask to the underlying substrate.

[1] Krishnamoorthy, S.; Manipaddy, K. K.; Yap, F. L. Adv. Funct. Mater. 2011, 21 (6), 1102–1112.

Designing a Conjugated Polymer Consisting of Phenyl-Oxazole Derivatives Using C-H/C-O Coupling

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Organic π-conjugated semiconducting polymers that have good electronic properties are very important in the development of organic solar cells. Traditionally, organometallic reagents are used in order to perform carbon-carbon coupling reactions of monomers to synthesize conjugated polymers. This requires stoichiometric amounts of organometallic compounds and additional synthetic steps compared to C-H activation chemistry in polymer synthesis. C-H activation eliminates the need to pre-functionalize the normally inert C-H bond found in many organic compounds with metals or other harsher reagents. The C-H activation will reduce byproducts, waste, and inorganic materials, which will aid in the development of "green" reactions. Itami, et al. found that easily synthesized phenol derivatives (containing a C-O-R electrophile) could activate the C-H bond in the 5-position of oxazoles to form a C-C bond. Our work is inspired by this, and the goal of this research is to draw from this methodology to design and synthesize a monomer that has both an electrophilic C-O-R group containing a phenyl ring and an oxazole such that it can undergo polymerization via C-H activation to make a donor-acceptor polymer. Future work includes the study of polymerization growth kinetics and its semiconducting properties.

Diverse Patterns and Geometries in Self-Assembled Block Copolymer Thin Films Through Multilayer Mixing

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Lithography via the self assembly of block copolymers is a promising tool for nanostructure fabrication on the order of 10nm. Once assembled, one block of the copolymer can be selectively removed and metal can be deposited on the remaining pattern. This can be used to create structures such as metal nanodots and highly connected metal nanowire networks with varying periodicities. The morphology of the block copolymer self-assembly is dependent on the volume fraction of each block in the copolymer. We present a technique called multilayer mixing, whereby we are able to change the morphology of block copolymer after the block copolymer has self-assembled, by increasing the volume fraction of one of the blocks. This is accomplished through spin casting a layer of homopolymer on top of the block copolymer and solvent annealing the new film to let it reach the equilibrium morphology. Previous work has shown that we can create microscale domains of block copolymer using standard optical lithography. The exposed regions of the chip are immune to multilayer mixing, retaining their original morphology even after homopolymer is spin cast. This allows us to place diversely patterned nanostructures on the same chip with high contrast and without any sacrificial layering.

Synthesis and Characterization of Size- and Shape-Specific Gold Nanocrystals for Superlattice Assembly

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Gold nanoparticles are useful in a variety of research technologies for biomedical, sensing, and imaging enhancement applications. In this work, gold nanoparticles of different shapes and sizes were systematically synthesized, characterized, and assembled. The best control over the size-distribution and morphology of the particles was achieved by using the seed-mediated growth method. By varying reaction and sample preparation conditions, gold nanocrystal growth was directed into various shapes. These nanocrystals were characterized using UV-vis spectroscopy, Scanning Electron Microscopy (SEM), and Transmission Electron Microscopy (TEM) to determine their final shape and packing structures. The amount of free ligand in solution and the concentration of seeds used in the growth solution resulted in visible differences in both nanocrystal morphology and their packing assemblies. Sample preparation conditions including drying temperature, drying speed, and droplet orientation were also investigated. By successfully controlling parameters in the reaction and sample preparation conditions, it is possible to synthesize uniform, ordered structures with tailored shape- and size-specific properties.

Magnetic Fano Interferences in Plasmonic Metal Oligomers

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Plasmonic metal nanoparticles possess exotic optical properties impacting a variety of fields from basic science to energy, defense, and medicine. One such property of broad importance is a Fano interference. This interference can be modeled by two coupled charged oscillators, in which the driven bright mode transfers its energy to the dark mode and stops. Thus, the system is still absorbing energy, but does not scatter. The resulting localization of energy is dependent on the coupling strength and mass ratio of the oscillators. These parameters, when properly tuned, alter the Lorentzian nature of the scattering spectrum, leading to an asymmetric Fano lineshape. The conditions that produce a Fano lineshape in the oscillator model were used to predict parameters in electric and magnetic plasmonic nanoparticle systems. This research focused on showing magnetic-magnetic Fano interferences for the first time. In particular, a magnetic plasmon was created from a cyclic assembly of metal nanospheres each with an electric dipole oriented head-to-tail around the ring, mimicking an electrical current loop. This is the ground state eigenmode configuration. A second plasmonic ring was coupled to the first and driven by an electron beam, and their resulting interference was studied through numerical simulations of Maxwell's equations.

Measurement and Management of Thin Film Stresses

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Metallization is a crucial step in microelectronic device fabrication. Stress in metal thin films is known to cause yield and reliability problems. In severe cases, improperly controlled stress can result in delamination, or layer separation, of the metal film. This project systematically studied the intrinsic stresses in TiW, W and Au films as a function of deposition conditions. The metal films are deposited on 2-inch (001) silicon wafers. Stresses in the metal films are derived by measuring the change in radius of curvature of the Si wafer after metal deposition and the thickness of the metal film deposited. This information is an important step toward controlling the stresses in the metal film to minimize the shear force at the metal/semiconductor interface and therefore improve device reliability.

Conformation of Organic Electronics to the Hemispherical Shape Using Elastomeric Transfer Elements

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A camera inspired by the human eye offers attractive design features for imaging devices. The hemispherical detector geometry enables a simpler and superior optical imaging system facilitating wide field of view with few-component imaging optics. Trends in research and product design are bringing forth bio-inspired, flexible and bendable applications of electronics such as the artificial eye camera. A successful hemispherical electronic eye camera based on single-crystalline silicon was previously built using elastomeric transfer elements to adapt the image sensor to the curvilinear surface. We have demonstrated a simple fabrication process with reduced cost that takes advantage of the flexible nature of organic electronics by constructing an image sensor using organic field-effect transistors. Using anodic dissolution to remove the polyimide substrate housing the organic image sensor from its carrier wafer and then integrating the organic image sensor into a hemispherical configuration using polydimethylsiloxane (PDMS) elastomeric transfer elements, the organic image sensor is conformed to the hemisphere. The transfer process demonstrated in this work can transform organic electronics on polyimide substrates into unconventional three-dimensional shapes that can be applied not only to the artificial eye camera but also to many bio-inspired applications to come.

Atomically Thin Films: Fabrication and Real-Time Electrical Characterization

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Atomic layer deposition (ALD) is presently employed in important semiconductor manufacturing processes, which include the deposition of ultrathin layers for gate dielectrics and diffusion barriers for interconnects. As many of the exciting applications of ALD involve forming ultrathin, atomically thin films, depositing a conformal and continuous ALD film with a controlled thickness is critical to performance. Moreover, the ability to assess their properties *in situ* is essential to avoid the complications that arise when samples are exposed to laboratory air. In this work, we designed and fabricated a substrate with patterned electrodes, which allows *in situ*, real-time electrical measurement of ALD film being deposited in a custom-build micoreactor. Fabrication of the substrate consisted of two patterned layers on thermal oxide: electron beam evaporated gold (with a chromium adhesion layer) followed by plasma-enhanced chemical vapor deposited (PECVD) silicon dioxide as insulating, protecting layer. Feature size and film morphology was confirmed by profilometer and scanning electron microscopy (SEM), respectively. To study the effect of air exposure on ultrathin film, a series of experiments, comprising of depositing platinum films with nominal thicknesses on the substrate and examining *ex situ* using IV probe station in a clean room, were conducted.

Magneto-Optic Characterization of Ferromagnetic Thin Films for Use in Nano-Scale Computer Applications

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Magnetic tunnel junctions (MTJs) utilizing materials with perpendicular magnetic anisotropy (PMA) are an attractive area of research due to applications in nanoscale computing. In particular, PMA facilitates spin-transfer-torque switching (STT) and high thermal stability in magnetic random access memory. While previous studies have shown that L10 ordered FePt films exhibit strong PMA, we illustrate that epitaxial Fe/Pt bilayers on MgO (001) can exhibit PMA if annealed after the initial deposit. All films were grown in the MBE system in the Palmstrøm Lab at UCSB. *In situ* Magneto-Optic Kerr Effect (MOKE) measurements were taken in the in-plane and out-of-plane directions to determine the magnetic anisotropy of each sample. In order to investigate the effects of annealing on interdiffusion and chemical reactions, we performed X-Ray Photoemission Spectroscopy (XPS) measurements on samples before and after annealing at different temperatures. Peak analysis shows a decrease in Pt peaks and increase in Fe with increasing annealing temperature, suggesting Fe outdiffusion into the Pt cap. Therefore, we suspect the formation of an ordered Fe-Pt phase between the Fe base layer and the Pt cap. We believe that performing X-Ray Diffraction (XRD) and Transmission Electron Microscopy (TEM) studies on future samples will give valuable insight into how annealing changes the crystal structure and affects compound formation.

Multidimensional Metal-Dielectric Plasmonic Array

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We present a new multi-dimensional plasmonic array consisting of a metal-dielectric-metal interface. This array enhances plasmonic interactions between layers and exhibits tunneling effects dependent on dielectric thicknesses. Plasmonic-driven growth is used to controllably fabricate the multi-layer nanogap structure. This multi-dimensional structure, which cannot be easily produced through conventional lithographic methods, takes advantage of plasmonic coupling effects and provides increased tunability of the optical resonance as well as greater enhancement of the near-field. In addition, we report high electric field focusing in the multidimensional plasmonic nanogap array, which confirms the enhancing nature of the structure and shows a potential for high sensitivity in detection applications. We demonstrate the uniformity and stability of the plasmonic structures through characterization of nanoparticle size and absorption spectra. Such a substrate can find uses in many areas, including optofluidic platforms for the detection of biological molecules such as proteins.

Study of Quantum Confined Nanostructures at Low Temperatures with Opto-Electronic Measurements

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Electronics which depend on transport of the electron spin rather than charge would potentially be faster and more energy efficient than traditional charge-based electronics. As magnets have an imbalance of electron spins, spin polarization in semiconductors can be achieved by injecting electrons from magnetic contacts into the semiconductor. Electrons confined in a two-dimensional sheet can show remarkable properties including very high mobilities, which is indicative of minimal electron scattering and a long mean free path, properties that are important for spintronic devices. Here, electrical measurements were performed to study electron transport in III-V compound semiconductors under intense magnetic fields (up to 9 Tesla) at cryogenic temperatures (down to 1.8 Kelvin). Quantum confined two-dimensional electron sheets formed in GaAs/AlGaAs heterostructures were simulated using a Poission/Schrördinger equation solver and then the heterstructures were grown by Molecular Beam Epitaxy (MBE). Electrical measurements were performed on Hall bar devices fabricated using photolithography. The Integer Quantum Hall Effect was observed in these devices and changes in electron mean free path, mobility, and density were studied with varying temperature and compared to the theoretical simulations. These results will be used to develop better material systems for next-generation electronics.

Temperature Dependence of Carbon Nanotube Growths

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Carbon nanotubes have unique electrical and physical properties make them a candidate for many different applications ranging from high-speed field-effect transistors to biosensors. For such applications, it can be crucial to grow arrays of aligned nanotubes at appropriate densities. In this project we explored how nanotube growth temperature is correlated with carbon nanotube density, nanotube diameter, and catalyst size. The nanotubes were grown by chemical vapor deposition (CVD) on ST cut quarts wafers using evaporated iron catalysts in a 5 inch diameter furnace. After every growth, samples were imaged using an SEM to determine the density of the carbon nanotubes, and then imaged by AFM to measure both nanotube diameter and catalyst particle size after growth. In the temperature range from 870°C to 910°C we observed a decrease in nanotube density as temperature increased. Conversely, the catalyst size increased from an average size of about 2nm to 4.5nm and the standard deviation increased by about a factor of 2. The mechanism responsible for increasing catalyst size is suspected to be Ostwald's ripening. The increase in catalyst size can also be used to explain an observed increase in nanotube diameter and the decrease in density at high temperatures.

Delta-Doping of Diamond

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The nitrogen-vacancy (NV) center in diamond has emerged as a possible versatile tool for data storage in quantum information processing. Consisting of a substitutional nitrogen atom located adjacent to a naturally occurring vacancy within the diamond lattice, the electron spins from the unbound electrons within the bond can be coherently controlled at room temperature and read out optically. The focus of this project was to determine the optimal conditions for NV center production in synthetic, polycrystalline diamond by growing and doping with N^{15} gas in a hot filament chemical vapor deposition reactor. The nitrogen isotope allowed us to distinguish our deposited nitrogen atoms from other impurities, such as N^{14} or Si atoms, that may also be present within the grown diamond. We introduced the nitrogen atoms at a 7 mm and 14 mm gap at different mass flow rates on synthetic diamond grown on silicon and silicon carbide substrates and deposited them as a top-surface dopant layer and sub-surface dopant layer. Our Raman microscopy data indicates that high quality diamond was grown with a full-width at half max of 7.6 cm^{-1} and previous confocal microscopy data has shown NV centers to be present within N^{14} doped diamond.

Growth of Graphene by Silicon Carbide Sublimation

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Graphene has become the material of choice for several investigators because of its desirably applicable properties. This two-dimensional "super-material" is hexagonally bonded in an sp^2 carbon arrangement. Successful methods for growing graphene include chemical vapor deposition (CVD) growth of graphene on metal surfaces like copper or nickel and graphene growth by sublimation on a silicon carbide (SiC) surface. Graphene on SiC is of particular interest because it does not require transferal onto another substrate like graphene grown on copper does and the process is not as strenuous and damage-prone. This work investigates the conditions necessary for forming graphene on C-terminated 6H-SiC crystalline wafers by sublimation. H_2 etching is performed at 1200°, while sublimation temperatures range from 1500°C-1700°C in the presence of argon gas, at a pressure of 200Torr with a flow rate of 5.0SLM. The growth times varied from 15-60 minutes. Scanning electron microscopy, atomic force microscopy and Raman spectroscopy were used to characterize the results obtained for single and multilayer graphene.

Smart-Cut Processing for Transfer of High-Temperature Ceramic Materials to Silicon

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Micromechanical resonator devices that naturally oscillate at certain frequencies are currently used in communication, signal processing, and sensor applications. Piezoelectric-based resonators, which utilize nonconductive materials such as ceramics, are commonly used for such applications and are historically constructed with a quartz material platform. However, applications with harsh surroundings, such as space environments, combustion engines, and down-hole drilling, can cause failure of quartz resonators at temperatures above 573°C due to phase change of the material and upon radiation exposure. Langatate, a high-temperature crystalline piezoelectric material, is well suited for resonator applications in these environments because of its inherent temperature stability and ability to remain piezoelectric at temperatures above 1400°C. Here, we are developing a microfabrication technique to place thin langatate films (approximately 1 µm) on a silicon substrate using the "Smart-Cut" process, which involves the exfoliation of a large portion of an ion-implanted langatate piece when heated to high temperatures. Results of spin-on glass bonding, measurements of the hydrophilicity of the langatate surface, and the analysis of the exfoliation of ion-implanted langatate will be presented. Thin-film single-crystal langatate on a silicon substrate can ultimately serve as a platform for the realization of micromechanical resonators for harsh environment applications.

Engineering the Fixed Charge of Al_2O_3 for Field-Assisted Passivation in Heterojunction Solar Cells

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Surface recombination is a detrimental phenomenon in heterojunction solar cells when electrons recombine with holes at defects in the interface between oxide and silicon due to differing crystal structures. The effects of surface recombination can be reduced through chemical and field-assisted passivation. Chemical technique improves the actual interface by rendering defects ineffective and is typically achieved through annealing. Field-assisted passivation involves placing a layer of high fixed-charge material adjacent to silicon, inducing the opposite charge within silicon. This charge creates an electric field that attracts opposite charge carriers and repels same charge carriers, thus preventing carrier interaction with surface defects. In this work, the viability of field-assisted passivation using aluminum oxide is explored by engineering a process that maximizes fixed charge. Different thicknesses of Al_2O_3 are deposited on n and p-type Si using plasma-assisted atomic layer deposition and metallized with tungsten or aluminum and titanium nitride. The capacitance-voltage (C-V) characteristics of the resulting structure are measured before and after annealing in forming gas. From the C-V curves, the flat band voltage is derived, and the fixed charge of Al_2O_3 is found. Based on these measurements, the suitability of Al_2O_3 for use in field-assisted passivation is evaluated.

Mechanical Testing of Flextrode: An ITO-Free, Transparent, Polymer Based Electrode

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Organic photovoltaic (OPV) cells may offer a means to rapidly produce low-cost devices by printing thin films onto plastic substrates in ambient conditions. Indium-tin oxide (ITO) is the standard electrode for OPVs, but is brittle, prohibitively expensive, and not scalable. The flextrode, a transparent, flexible electrode composed of conductive polymers, was recently developed as a move towards cheaper materials with better mechanical properties than ITO. This project investigated effects of mechanical strain on the cohesion and function of the flextrode as part of an OPV. Films on a plastic substrate were deformed to varied strains, while monitoring film behavior with an optical microscope. Changes in surface morphology were characterized with optical and atomic force microscopy to determine the strain tolerance of the films. Additionally, in-situ measurement of conductivity and photovoltage during tensile tests determined the effect of strain on the functionality of the layers. The flextrode proved to be a mechanically robust, viable alternative to ITO that resists cracking up to 25% strain with minimal loss of conductivity. Replacing ITO as the OPV electrode is a step towards scalable production of cheap, flexible solar cells.

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ABSTRACTS

in alphabetical order by last name

An Electronic Textile Process for Health Monitoring Sensors

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Wearable electronic textiles are good candidates for achieving low cost, flexible, and light-weight health monitoring devices. The integration of biocompatible organic polymers, such as poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS), and ionic gels with textiles allows for the development of conformable and high performance electronics for cutaneous applications. For these reasons, we developed a fabrication process for PEDOT:PSS based electrodes. Such electrodes were used for recording electrocardiography (ECG) activity and for developing an electrochromatographic display of such activity. An ionic gel was used to aid in the electrochemical doping and de-doping of the PEDOT:PSS electrodes. Color changes on the electrochromatographic display were analyzed via optical spectroscopy. The PEDOT:PSS electrodes were also used as capacitive pressure sensors, with polydimethylsiloxane (PDMS) as dielectric, for physiotherapeutic applications. Results obtained using this process provide promising technology which can be further integrated on an electronic textile glove that can perform several health monitoring tasks at once.

Synergistic Effect of Adhesive Ligand Density and Soluble Factor TGF-β on EMT Progression

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Characterized by a change in cellular phenotype and an adjustment in protein expression, the epithelial-mesenchymal transition (EMT) describes the transformation of epithelial cells into a mesenchymal cell type. This transition is believed to occur in the initial stages of cancer metastasis as it enhances the migratory capacities and evasiveness of individual cells [1]. Therefore, by controlling the progression of EMT, we can potentially control the progression of metastasis itself. In this study, we aim to evaluate the impact of two factors—surface density of an extracellular matrix protein-derived ligand and soluble transforming growth factor-β1 (TGF-β)—on the progression of EMT. Gold surfaces coated in various ratios of adhesive ligand cRGD: bio-inert EG were seeded with epithelial cells. Culture medium was supplemented with TGF-β to promote EMT progression on the surfaces; this progression was measured using morphological analysis and immunofluorescence staining. Ultimately, cells grown with TGF-β on low-density cRGD exhibited mostly mesenchymal phenotypes, indicative of accelerated EMT. Additionally cells grown with TGF-β on high density cRGD exhibited only partial EMT while cells grown without TGF-β on high-density cRGD exhibited mostly epithelial phenotypes, indicative of delayed EMT.

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SERS Study of BNNS on Au as a Catalyst for Oxygen Reduction Reaction

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Non-precious-metal catalysts for the Oxygen Reduction Reaction (ORR) in fuel cells are in high demand to decrease fuel cell cost and increase cathode stability. One candidate for an ORR catalyst in fuel cells that use an acidic electrolyte is Boron Nitride Nanosheets (BNNS). In order to identify surface intermediates during the reaction and better understand the potential of BNNS as a catalyst, *in situ* measurements of BNNS on Au during the reaction were done using an electrochemical cell setup and Raman spectroscopy.

Au was used as a supporting material to facilitate semiconducting properties of BNNS, which was drop-casted on the surface of the substrate. The electrolyte used was 0.5 M H_2SO_4, the reference electrode was Ag/AgCl, and the counter electrode was Pt wire. The substrates were chemically roughened using reduction cycles in KCl to increase surface enhancement during the measurements, a process known as Surface Enhanced Raman Scattering (SERS). Additionally, gold nano particles were introduced into the BNNS solution. After these modifications, potential-dependent spectra were obtained and new peaks were observed during the reaction. Future work will include repeating measurements for reproducibility, and further study of the peaks to identify surface intermediates.

Fully Printed Organic Electrochemical Transistor on Paper for Glucose Sensing

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Inkjet printing of conductive polymers is a simple, low-cost, and non-contact fabrication method for bioelectronic devices. In this study, an all-plastic glucose biosensor based on an organic electrochemical transistor (OECT) was printed on a paper substrate. An aqueous bioelectronic ink consisting of the conductive polymer poly(3,4-ethylenedioxythiophene)-poly(styrene sulfonic acid) (PEDOT:PSS) was used to print the source, drain, channel, and gate of the transistor. An ink containing chitosan/ferrocene solution was also printed to functionalize the PEDOT:PSS gate. Bioenzymatic sensing of glucose was then completed with these devices by using glucose oxidase (GO_x) and phosphate buffered saline (PBS) as the enzyme and electrolyte, respectively. The ferrocene on the device acts as an electron shuttle from GO_x to the PEDOT:PSS gate, causing de-doping of the channel and a corresponding decrease in drain current that is dependent on the concentration of glucose in solution. Initial results show glucose detection between 2.70 and 14.29 millimolar, consistent with the concentration in human blood. Further manipulation of the device could lead to detection down to the micromolar range, which is close to that in human saliva. This device could then be used as a daily noninvasive glucose monitor for diabetic patients.

Twisting a C=C Double Bond in Crowded Alkenes: The Synthesis and Characterization of Small Molecule Electron Acceptors

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One of the major objectives for materials science is the optimization of the performance of organic photovoltaic devices (OPVs). In such devices, an appropriate combination of donor and acceptor materials is necessary for efficient charge separation and migration. While several research groups have recently reported a wide range of new polymeric donor molecules, there have been fewer reports on new structures of acceptor molecules. Most current acceptor molecules contain fullerene derivatives – however, due to their difficulty in synthesis and purification, along with their weak absorption in the visible region, the synthesis of new and versatile acceptor molecules is urgently required. There is an inherent potential in acceptor molecules based on 9,9'-bifluorenylidene (9,9'-BF), as the addition of one electron to 9,9'-BF is believed to be a highly favorable process due to steric strain relief and gain in aromaticity to a 14π electron system. The purpose of this study was to synthesize and characterize a series of novel 9,9'-BF derivatives that differ in the twisting angle of the central C=C double bond but are similar in other electronic properties. The twisting angle of each 9,9'-BF derivative was correlated to its bandgap and redox properties, which were determined by UV-vis spectroscopy and cyclic voltammetry, respectively.

Characterization of Graphene Growth on Pt (111)

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Characterization of sizable graphene sheets grown on metal surfaces is key to understanding the interaction between graphene and the substrate for future applications. It is confirmed by Auger electron spectroscopy (AES) and helium ion microscopy (HIM) that graphene was successfully grown on Pt (111) surface through segregation. The graphene consists of single-layer graphene across the majority of the substrate with various sections of bi- and tri-layer graphene islands and Pt patches. X-ray photoelectron spectroscopy (XPS) reveals the C1s peak from graphene on Pt (111) has lower binding energy than those from graphite (HOPG) and graphene on Ni (111), suggesting that graphene on Pt (111) has a weaker interaction than other substrates. Topographic images and cross-section data from atomic force microscopy (AFM) depict that graphene islands are 1.10 nm lower than the surrounding Pt region, in spite of the fact that graphene is grown on Pt. This observation speculates that water adsorption on the Pt region may indicate the nanoscale hydrophobicity of graphene and nanoscale hydrophilicity of Pt (111).

Small Interfering RNA Delivery for the Treatment of Hereditary Bone Disease

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Ostoegenesis Imperfecta (OI), commonly known as Brittle Bone Disease, is a congenital bone disorder in which bones are hyper vulnerable to fracture. Of the eight different classification types, Type V is contingent on the gene that encodes for interferon induced transmembrane protein 5 (IFITM5). IFITM5 protein is a positive regulatory factor for bone mineralization *in vitro*, but recent studies have suggested that IFITM5 protein is not necessary for normal bone growth and maturation *in vivo*. The protein is expressed in all osteoblasts, but osteoblasts in patients with OI Type V express a mutant protein with five additional amino acids at the N-terminus. This modification is believed to be the cause of OI Type V. The focus of this project is to suppress the expression of the modified protein using small interfering RNA (siRNA). Different transfection methods were used to determine an effective protocol for delivering siRNA in vitro, and suppression was quantified using qPCR.

Optimization of a Capacitive Sensing Organic Electrochemical Transistor Immunoassay

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The development of rapid detection immonoassays is of major interest to biological research and the medical field. This project focuses on creating an organic electrochemical transistor (OECT) based immunoassay that operates via the capacitive change caused by antigen-antibody affinity binding to biofunctionalized molecules on the OECT channel. When molecules are immobilized to the poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) based transistor channel, they add a resistive and capacitive element to the equivalent circuit. The impedence changes due to the added mass to the channel and a complex combination of electrostatic charges are reflected in a shift in transconductance. The antigen protein was immobilized on the transistor channel on a layer of (3-Glycidyloxypropyl)trimethoxysilane (GOPS) on the channel surface. Binding effects were validated via both fluorescence and electrical measurements. In order to be sensitive to small changes in impedence, the effect of the concentration of electrolyte, a resistive property, was explored by testing the transistor under varying concentrations of PBS solution. Covalent binding from the biofunctionalization of the channel can be detected in the transconductance shift in the transistor under the low electrolyte concentration in phosphate-buffered saline (PBS) 0.001X. These initial results show the potential of our proposed method towards the development of sensitive immunoassays based on OECT.

Investigation of the Thermoelectric Properties of Boron Carbide-Hafnium Diboride Composite Materials

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Boron Carbide-Hafnium Diboride composites were prepared by spark plasma sintering of a mixture of Hafnium Diboride powder and Boron Carbide powder. The Boron Carbide powder was prepared with a 13.3 wt % composition of carbon, which a previous study found to be the ideal carbon content for the dimensionless figure of merit [1]. The Hafnium Diboride content was varied between 0 and 20 percent by weight and the effect on the thermoelectric properties were studied. The samples were characterized using x-ray diffraction (XRD). The electrical resistivity and Seebeck coefficient were measured using the 4-probe method and differential method, respectively. The thermal conductivity was measured by the laser flash method. The optimal Hafnium Diboride content was found to be 10 wt %, leading to an improvement in the figure of merit ZT from 0.188 for the non-composite material to 0.200 for the 10 % wt HfB_2 composite at 730 °C.

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Carbon Materials Assisted ZnO Nanowire Array Composites for Enhanced Photoelectrochemical Water Oxidation

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Achieving total photoelectrochemical (PEC) water splitting can help combat the energy crisis by providing clean alternative fuels. However, total water splitting is difficult due to the slow reaction rates of the water oxidation half reaction and recombination of photogenerated electron-hole pairs in semiconductor photocatalytic materials. In an effort to enhance water oxidation kinetics, ternary structured ZnO nanowire (NWs) array composites were investigated. ZnO NWs arrays were grown via hydrothermal synthesis, electrodeposited with Co3O4 as the co-catalyst, and then loaded with carbon materials to achieve ternary ZnO-Co_3O_4-Carbon structures to prevent electron-hole recombination and increase reaction rates. Initial PEC testing indicates that adding a co-catalyst and multi-walled carbon nanotubes (MWCNTs) enhances PEC water oxidation currents when compared to pristine ZnO NWs photocurrents. At a potential of 0.6 V vs. Ag/AgCl (1.23 V vs. RHE), the PEC water oxidation current of ZnO-Co_3O_4-MWCNT NW arrays measured was 1.61 mA which is nearly double the photocurrent achieved by pristine ZnO NWs (0.8618 mA). These results demonstrate that the Co_3O_4 co-catalyst in combination with MWCNTs promote electron-hole pair charge separation, a feature essential for water oxidation. Lastly, hierarchical graphene oxide-ZnO-Co_3O_4 NW array composites were fabricated to investigate how 1D-ZnO-2D-GO influences the photoelectrochemistry of water oxidation.

Quantum Dot Superlattice Hybrid Structures for Solar Cell Applications

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Using quantum structures (QSs) in the absorption layer of a solar cell has been of great interest in potentially overcoming the Shockley-Queisser conversion efficiency limit of solar cells. QSs produce an intermediate band (IB) which allows absorption of sub-bandgap photons and thus increases photocurrent generation. A hybrid quantum dot (QD) quantum well (QW) structure was proposed to create intermediate energy states. This hybrid structure is expected to provide advantages of both QWs and QDs. QDs afford a discrete density of states while QWs allow a relatively large absorption of photons. A superlattice (SL) structure of ten QWs was realized from GaAs and AlGaAs. QDs were grown on top of this structure using a thin layer of InAs. Samples were grown using molecular beam epitaxy (MBE). To create solar cells these samples were then fabricated using photolithography, sputtering, and chemical etching. Photoluminescence measurements were performed for optical characterization which revealed that carrier transfer between the SL and QD structures occurs as designed. Low temperature current-voltage (IV) measurements indicate that carrier trapping can occur. However, room temperature (RT) current-voltage measurements demonstrated that all carriers escape from QSs at RT. More study must be done to reveal this proposal's possibilities as an IB.

Influence of Cell Spreading Area on Uptake of Gold Nanoparticles

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Nanoparticles (NPs) have been proved to be a promising material for drug delivery, cancer therapy, and bioimaging. However, there is growing concern about their cytotoxicity which may cause an inverse effect on human health. In order to develop safer and efficient NPs, people need to fully understand how cells react with the NPs. Previous studies investigated the influence of NPs properties on cellular uptake. However, little attention was paid to understand the influence of cell membrane tension on the uptake. Micropatterns were used to control the membrane's tension on single cell scale; the greater the spreading area, the greater the tension on the cell membrane [1]. Thus in this study, a serious of microdots with various diameters (20, 40, 60, and 80 µm) were developed using photolithography techniques. Gold nanoparticles (AuNPs) with size of 50 nm were synthesized following the Turkevich method, and coated with FITC labeled PEG. Mesenchymal Stem Cells (MSCs) were cultured on micropatterns and treated with FITC-PEG-AuNP to investigate the influence of cell spreading area on uptake of NPs. The results indicated that PEG coated AuNP showed non-toxic to the MSCs. Patterned cells with different spreading areas and cellular tension can uptake the FITC-PEG AuNPs.

[1] Biophysical Journal, 94, 4984, 2008.

Optimizing Insulator Layer Deposition for Diamond MOSFETs

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Field effect transistors (FETs) are important components in electronic devices due to their ability to act as electrical switches. They are comprised of a source, drain, and gate and there must be enough energy potential difference in order for the carriers, electrons or holes, to flow from the source to the drain. One of the ways the effectiveness of these devices can be improved is by applying an insulator or oxide layer on top of the channel layer in order to reduce the number of carriers that escape through the gate contact. In the case of this research, diamond substrates with hydrogen-terminated surfaces were used due to their high availability of holes. The oxide layer used was aluminum oxide (Al_2O_3) which was deposited at various temperatures by the atomic layer deposition technique. The electrical properties of the Al_2O_3/H-diamond based metal-oxide-semiconductor (MOS) diodes and MOSFETs were studied. It was found that an ideal deposition temperature for the Al_2O_3 is 300°C because it produces ideal capacitance-voltage behavior without flat-band shift in the MOS-diode devices. The MOSFET showed good operation with normally-on, ohmic characteristics.