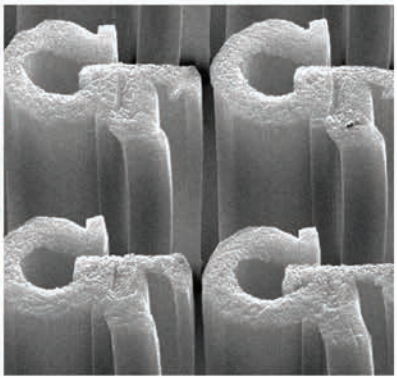
The 2014 NNIN REU Convocation

NNIN
Nanoscale Science, Engineering & Technology

August 10-13, 2014

Georgia Institute of Technology



Georgia Tech Institute for Electronics and Nanotechnology

2014 NNIN REU Convocation

Georgia Institute of Technology, Atlanta, GA

•• Sunday • August 10, 2014 ••

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

6:00-8:30 p.m. Trivia Hour, Welcome and Pizza Party, Marcus Nanotechnology Building 325 Ferst Drive

•• Monday • August 11, 2014 ••

7:00-8:00 a.m. Breakfast for Interns at Hotel *(none at convocation)*

8:30- 8:40 a.m. Welcome by Dr. Stephen E. Cross, Executive Vice President for Research, Clough Commons Room 152

Session A; Clough Commons Room 152 (6 talks)

Moderator: Michael Deal

9:46-10:06 a.m. Break

Session B; Clough Commons Room 152 (5 talks)

Moderator: William Rose

11:01-11:16 a.m. Break

Session C; Clough Commons Room 152 (4 talks)

Moderator: Paul Neubert

12:00-1:00 p.m. Lunch at Stamps Student Center *(voucher needed)*

Session D; Clough Commons Room 152 (7 talks)

Moderator: Sandrine Martin

2:22-2:42 p.m. Break

2:42-3:07: Dr. Lynn Rathbun, Presentation on Fellowships; Clough Commons Room 152

Session E; Clough Commons Room 152 (7 talks)

Moderator: Kathryn Hollar

Adjourn 4:25 p.m.

7:00 – 10:00 p.m. Evening Event
Game Room and BBQ at the Student Recreation Center

•• TUESDAY • AUGUST 12, 2014 ••

7:00-8:00 a.m. Breakfast for Interns at Hotel *(none at convocation)*

8:30-8:35 a.m. Announcements, Clough Commons Room 152

SESSION F.; CLOUGH COMMONS ROOM 152 (6 TALKS)

Moderator: Trevor Thornton

9:41-10:21 a.m. Panel Session on the iREU Program

France: Dakota Crisp and Ashlyn Young

Japan: Arthur Bowman, Samantha Corber, Tiffany Huang, Megan Kazanski, Gabriel Lopez Marcial, Peter Su, Jill Wenderot, Connie Wu, Allison Wustrow

10:21-10:41 a.m. Break

10:41-11:41 p.m. Panel Session Careers

Participants: Thomas Averret-Johnson, Georgia Tech; Dan Benjamin, NextInput, Inc.; Amy Bonecutter, Lumense, Inc; J.P. James, Libreum International; Kenyetta Johnson and Christine Taylor, Georgia Tech

11:41-1:00 p.m. Lunch and Group Photographs at Clough Commons ***(box lunch)***

Session G; Clough Commons Room 152 (6 talks)

Moderator: Nancy Healy

2:06-2:26 p.m. Break

Session H; Clough Commons Room 152 (5 talks)

Moderator: Melanie-Claire Mallison

3:21-5:00 p.m. SEI Panel/Activity; Jamey Wetmore, Director of NNIN's SEI Program, Arizona State University

5:00 p.m. Adjourn

6:00 – 9:00 p.m. Evening Event
Viva Las Vegas in the Marcus Nanotechnology Building

•• Wednesday • August 13, 2014 ••

7:00-8:00 a.m. Breakfast for Interns at Hotel *(none at convocation)*
8:30-8:35 a.m. Announcements, Clough Commons Room 152

Session I; Clough Commons Room 152 (6 talks)

Moderator: Jim Marti

9:41- 10:01 a.m. Break

Session J; Clough Commons Room 152 (5 talks)

Moderator: Lynn Rathbun

10:56-11:16 Break

Session K; Clough Commons Room 152 (5 talks)

Moderator: Kathy Gehoski

12:11-1:15 Lunch at Stamps Student Center *(voucher needed)*

1:15 - 1:25 p.m. Poster Session I set up Last Names A-L

1:25-2:35 p.m. Poster Session I

2:35 - 2:45 p.m. Poster Session II Set up Names L-Z

2:45 -3:55 p.m. Poster Session II

4:00-4:15 p.m. Wrap up and adjourn

Evening on Your Own!

•• Thursday • August 14, 2014 ••

7:00-10:00 a.m. Breakfast for Interns at Hotel

Check Out by 12:00 Noon!

The iREU Research Abstracts

2014 NNIN REU Convocation

at the

Georgia Institute of Technology

Presentation Abstracts

(In Order of Presentation)

&

2014 NNIN iREU Research Abstracts

Fabricating Heavy Metal/Ferromagnetic Bilayers for Spin Torque Applications

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Magnetic devices are leading contenders for future non-volatile memory and logic implementations. Applications for magnetic devices will require the development of efficient mechanisms for reorienting their magnetization. Spintronic devices use spin currents to exert a torque on the ferromagnetic layer, causing its magnetization to reorient. When a charge current flows through a metal with a strong spin-orbit coupling, the spin Hall effect creates a spin current transverse to the charge current direction. This spin current applies a torque to an adjacent ferromagnet. Topological insulators, which have surface states with large spin-orbit coupling effects, are promising options for spin current sources. Previous research has shown that the topological insulator Bi_2Se_3 efficiently generates spin currents. However, due to the high resistivity of Bi_2Se_3, much of the charge current in a Bi_2Se_3/Permalloy device flows through the low resistivity Permalloy (Py) and does not contribute to the torque. This issue can be resolved by using an insulating ferromagnet. We are working to develop a new method capable of measuring spin torques acting on insulating ferromagnets by using waveguide spin pumping and a magneto optical Kerr effect (MOKE) microscope. We will present initial measurements of Pt/Py test devices from the MOKE microscope.

Investigation of Nanodiamond Foil Product for H- Stripping to Support Spallation Neutron Source

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Diamond is an ideal material as an H- stripper foil for spallation neutron source (SNS) applications due to its high thermal conductivity, low molecular weight, and strength. Polycrystalline diamond is characterized by a high degree of internal stress, which causes the foil to curl when not supported by the substrate. Hot filament chemical vapor deposition (HFCVD) was used to grow diamond on a silicon substrate. A 1.2 cm diameter window was etched in the silicon using a 1:1:3 solution of hydrofluoric, nitric, and acetic acids so that the diamond foil would be suspended while being supported on all sides by the silicon. Wax and diamond were used as masks to protect the outer silicon from etching. Raman spectroscopy verified a high quality diamond foil. Atomic force microscopy (AFM) revealed that the foil originally against the substrate had an average roughness of 6.7 nm while the foil away from the substrate had an average roughness of 13.2 nm. Scanning electron microscopy (SEM) revealed no cracks in the suspended foil.

Particle Sorting on Microfluidic Chips Using Optical Forces

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When light interacts with matter, it is capable of transferring linear and angular momentum. It is understood that plane waves incident on a particle will push the particle in the direction of light propagation, and that circularly polarized light can rotate particles about their centers of mass. The goal of this project is to design an apparatus capable of sorting particles using optical forces. Several flow chamber designs were constructed of polydimethylsiloxane (PDMS) and tested for sorting ability. The flow chamber channel widths range from 15 to 100 μm with depths of 15 μm ending in a fork with an angle between 10 and 25°. Flow chambers were tested by feeding five-micron diameter polystyrene beads through the flow chambers with and without the presence of radiation pressure perpendicular to the direction of flow. At the fork, the beads proceed down either the left or right channel. The change in the distribution of the beads at the fork is a measure of the flow chamber's ability to sort particles using optical forces.

Directed Assembly of Nanowires in AC Fields: Tuning Electrical Properties and Field Strength to Achieve Ordered Arrays

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Nanowires form a fascinating topic of inquiry in modern research and offer material properties that are advantageous in fields such as next-generation electronics, solar cells, and optics. When left to self-assemble, nanowires tend to become trapped in metastable assemblies where wire directionality is inhibited by forces such as gravity and solvent interactions. This project explores the introduction of an alternating current (AC) electrical field on particle assembly to order nanowires into nonrandom and reproducible arrangements. Particles were controlled via dielectrophoresis, where induced dipoles oriented wires towards electrode edges and eventually organized them into larger assemblies. The gold electrodes used in experiments were fabricated lithographically using a patterned mask through which the design was projected onto a cover slip coated with positive photoresist. Designs maximized areas of field strength and thus concentrated wires, allowing close-range attraction forces to dictate the assembly process. The nanowires were synthesized through electrodeposition into a porous alumina membrane. This bottom-up method allowed for great versatility in nanowire design, where segments of different materials could be deposited sequentially to create different patterns. A deeper grasp on fundamental nanoparticle behavior could open the possibility of creating ordered assemblies based on rationally-designed wires in the future.

Fabrication of Diamond Microwires for Quantum Information Processing Applications

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The nitrogen-vacancy (NV) center in diamond has recently emerged as one of the potential candidates for quantum information processing applications due to its good coherence properties. However, interaction with the environment leads to decoherence — loss of quantum state. It has been reported that nanowire structures reduce interaction with the environment and increase coherence time. The purpose of this project was twofold: (1) grow and characterize diamond on silicon wafers, and (2) fabricate diamond microwires using photolithography and electron-beam lithography. The hot filament chemical vapor deposition (HFCVD) system was used to grow nanocrystalline diamond on silicon wafers. Lift-off resist (LOR) 10B from MicroChem Corp. and Microposit S1818 from Shipley were used for a bilayer photoresist process followed by chrome (Cr) evaporation and liftoff process. An etch-back process was also studied to generate Cr patterns. Reactive-ion etching was used to etch diamond with an oxygen plasma with an etch rate of ~ 15 nm/min. We achieved ~ 3 μm sized diamond cylinders, which were characterized using scanning electron microscopy (SEM) and atomic force microscopy (AFM).

Development of Diamond-Like Carbon Deposition Processes and Microfabrication of Thin-Film Ag/AgCl Reference Electrodes

Christopher Davidson
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The ability to track neurotransmitters at a cellular level could greatly expand our understanding of the brain. To do this, however, we need to make safe, implantable devices that can sense activity at this level. Two aspects of this idea were focused on in this research project: a) the use of diamond-like carbon (DLC) as a biocompatible coating for these devices, and b) the fabrication of thin-film Ag/AgCl electrodes to measure concentration of neurotransmitters. Due to its favorable properties, DLC could reduce glial scarring and improve durability of these sensors. Thin films were deposited using different gas mixtures of CH_4 with N_2, He, or Ar by an rf-plasma enhanced chemical vapor deposition (PECVD) system. The deposition rates for each gas mixture was found and the films were then characterized by Raman spectroscopy. Unfortunately, it was found that only amorphous carbon was formed during this process. However, annealing said samples at 600°C for 30 minutes in a sealed ampoule was shown to form DLC. After this was done, microfabrication of a Ti/Pd/Ag/AgCl/KCl-gel solid-state electrode was completed. These electrodes can be used to measure concentration of different neurotransmitters in the brain through cyclic voltammetry.

Direct Writing for Biological Applications: Cell Patterning into Microfluidic Channels and Nanoparticle Writing onto Patterned Substrate

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Direct writing is an alternative method used to print biological fluids in a micro setting when they cannot stand conventional lithography. This project presents two applications of using the Dimatix Inkjet printer. Two-phase cell patterning is a completely aqueous method of patterning cells using the immiscible polymers dextran and polyethylene glycol (PEG) [1]. The goal of the first project was to ink-jet print dextran on microfluidic channels channels and examine its behavior with the addition of PEG. In the second project, we printed quantum dots (QDs) on an SU-8 patterned wafer. This will be incorporated in a microelectromechanical systems (MEMS) device to be implanted into the skull in order to measure intracranial pressure. Different pressures cause one layer of QDs to fluoresce more intensely than the other [2]. Direct printing of QDs was examined as an alternative method that would be quicker and use less material than the previous method of spinning the QDs mixed with the photoresist (SU-8).

References:
[1] Frampton, J. P., et. al. Cell Co-culture Patterning Using Aqueous Two-phase Systems. J. Vis. Exp. (73), e50304, doi:10.3791/50304 (2013).
[2] Ghannad-Rezaie, Mostafa, et. al. "A near-infrared optomechanical intracranial pressure microsensor." J.of MEM systems 21.1 (2012): 23-33.

Fabrication of Nanochannels for Linearization and Diffusion of DNA

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Optical mapping of deoxyribonucleic acid (DNA) has emerged as a viable alternative to help with read length restrictions in conventional sequencing. Rather than attempting whole genome sequencing, which often has errors and gaps, optical mapping uses fluorescent imaging of large (~10 kbp-1 Mbp), linearly arranged, individual DNA strands in order to view large scale patterns that would be difficult to obtain by sequencing [1]. The difficulty with optical mapping is forcing the DNA to be in a linear state, since its maximum entropy is a random coil state. The focus of this project is to study how a strand of DNA behaves while confined by a nanochannel, specifically its extension and diffusion properties in response to the variation of width of the channel. Each device consists of same-sized nanochannels, with sizes varying per device. Since individual DNA strands are difficult to confine directly from bulk, etched microchannels feed the DNA into the nanochannels. Each device is fabricated from fused silica substrate, and both photolithography and e-beam lithography are used to create the patterns on the resist. Reactive ion etching consisting of Ar, CF_4, and CHF_3 is conducted to etch the actual channels into the wafer.

References:
[1] Lam, E.T. et al. (2012). Genome mapping on nanochannel arrays for structural variation analysis and sequence assembly. Nature Biotech., 30(8), 771-776.

Fabrication of Nanoplasmonic Devices

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Nanohole arrays patterned in noble metal films can function as optical biosensors, because the optical transmission through the nanoholes changes sharply with refractive index changes near the metal surface. Smaller nanoholes have sharper resonance peaks, making a better sensor. At the same time, smaller nanoholes have lower transmission efficiency. Template-stripped Ag nanohole arrays of varying diameters were used in combination with an ultra bright white light source to look at the difference in the optical response of nanoholes with a diameter of 80 nm in comparison to nanoholes with diameters of 100 and 120 nm. To achieve the resolutions needed for the nanohole arrays, electron beam lithography was used to pattern them. Electron-beam lithography was also used to manufacture a mask on a suspended nitride film for metal deposition. Using this technique allows the user to manufacture a number of chips with a mask, minimizing the use of the electron beam. The devices created by this process used metal-oxide-metal tunnel junctions. The resonant frequency of this plasmonic device can be tuned by changing the dimensions of the metal grating.

Developing a Novel Microfluidic Device Allowing for the Study of Molecular Communication Between Two Bacteria Colonies on a Single Chip

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Understanding the molecular communication between bacteria is a key component in building biosensors that utilize genetically modified bacteria. Currently, we have the capacity to study one receptor bacterial colony's response to an artificial chemical signal via microfluidic device; however, studying the communication between two bacterial colonies is key to improving the robustness of biosensors. This project focuses on creating the first microfluidic device that allows for the study of various communication schemes (e.g. pulses, step functions) via an aqueous signal between sending and receiving bacterial colonies on one chip. Using the geometry of our channels, we designed a device in which our computational models show a chemical signal retention of 30.6%. Modifying existing protocols for UV photo-patterning of a porous polymer monolith, we created a process that allows for the insertion of a polymer monolith filter with submicron pores between bacterial chambers, intended to allow diffusion of the chemical signal and separation of the two bacterial colonies.

Microtensiometers with Patterned Porous Silicon

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Our MEMS-fabricated tensiometer can measure the water potential in soils and plants directly as pressure. It measures the pressure in an internal water-filled cavity that equilibrates with the measured media through porous silicon (PoSi), a layer of nanopores electrochemically etched on a silicon wafer. In previous versions of the microtensiometer, PoSi connected the cavity with the perimeter of the whole sensor, thus the sensor equilibrated with all its surroundings. In this project, we decreased the measured area by pattering the PoSi. This allows the sensor to be used as a probe with high spatial-resolution. Following the protocol of Ohmukai [1], we used photolithography with image reversal to pattern the PoSi. We modified the PoSi etching recipe since the area coverage was less than the normal one. We used the same current density 20 mA/cm^2, so instead of using 900 mA, we used 12 mA for five minutes with a solution of 1:1:2 HF:water:ethanol. We will report on the characterization of the patterned membranes by optical and electron microscopy and the formation of test devices based on anodic bonding with glass. We will conclude with our measurements of permeability of the patterned membranes and perspectives for future experiments and applications.

References:
[1] Ohmukai, M., et al. Patterned porous silicon formed with photolithography. J. Mater. Sci. 16, 119–121 (2005).

Aluminum Oxide for Surface Passivation in Photovoltaics

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With solar energy becoming more and more prominent in the global energy sector, improving conversion efficiency within the silicon solar cells is critical. Two factors that significantly reduce the performance of a cell are recombination at the surface and recombination within the bulk defects. Together, these limit the amount of effective carriers in the cell and therefore affect the amount of current and voltage the cell can output. Reducing surface recombination is especially important because wafers are becoming thinner in order to reduce costs of production. As the thickness decreases, the surface area to volume ratio greatly increases, and surface recombination becomes a leading limiting factor in efficiency. If we can reduce the effects of this recombination, we can furthermore study the general quality of the silicon bulk, in which defects contribute to lower minority carrier lifetime. In order to study the influence of chemical cleaning processes and surface passivation on p- and n-type silicon wafers, wafers were first etched for saw damage using either an acid or base solution. Then wafers were deposited with aluminum oxide thin films using atomic layer deposition. The minority carrier lifetime in each instance was then measured using a quasi-steady state photoconductance lifetime tester, both before and after annealing the samples.

Cohesion and Adhesion in Thin-Film Organic Nanostructured Materials for Photovoltaic Applications

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The main focus of this project is to study the nano-mechanical properties, cohesion and reliability of advanced thin-film architectures used in organic photovoltaics. Photovoltaics is the direct conversion of sunlight into electricity at the atomic level. The cohesion of the photoactive layer, which consists of the polymer poly(3-hexylthiophene-2, 5diyl), or P3HT and small molecule phenyl-C_{60}-butyric acid methyl ester, or $PC_{60}BM$, can be characterized using micromechanical analysis. The goal of this work is to develop an understanding of how the films adhesive/cohesive and thermo-mechanical properties are related to their nanostructure and processing conditions. In addition, we will be using a cross-linking agent to minimize molecular diffusion, improving thermal stability. In particular, we will be interested in how the films are affected under operating conditions which will include exposure to air, solar UV irradiation, and temperature. We will use a number of characterization techniques such as adhesion/cohesion testing, x-ray photoelectron spectroscopy, scanning electron microscopy, and atomic force microscopy to analyze the failure pathways within the prepared photovoltaic cells. By correlating the results to the efficiencies for our organic photovoltaics and analyzing the trends, we intend to design processing methods that will improve the mechanical reliability of these devices while maximizing thermal stability.

Developing Methodology for Living Polymerization of Functionalized Conjugated Monomers using Ni Catalysts with Electron-Rich Phosphine Ligands

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The potential applications of polymers in the semiconductor industry have spawned further research into developing their synthetic routes. Organic semiconductors are poised to revolutionize the electronics industry because the devices made using organic semiconductors are inexpensive to fabricate when compared to their traditional silicon counterparts. One difficulty associated with polymer synthesis is molecular weight control. Living polymerization, a form of chain growth polymerization that allows for precise control of molecular weight and dispersities, has been shown to potentially solve this issue. Methods such as the Kumada Ni-Catalyzed Transfer Polymerization allow such control through the adjusting of monomer to catalyst ratios. Also problematic of polymer synthesis is the use of toxic organometallic monomers. This may be solved by involving C-H functionalization, eliminating the need for organometallic monomers, and reducing overall environmental impact. Recent reports [1] of C-H/C-O biaryl coupling of benzoxazoles via Ni(0) with electron-rich phosphine ligands have inspired our approach towards a living polymerization methodology with functionalized conjugated benzoxazole monomers. Currently, synthesis of monomer precursors have proven successful as shown by HNMR data.

References:
[1] Nickel-Catalyzed C-H/C-O Coupling of Azoles with Phenol Derivatives. Muto,K.; Yamaguchi, J.; Itami, K. J. of ACS. 2012, 134, 169-172.

Doping in Spray-Deposited Iron Oxide for Next-Generation Photovoltaics

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The purpose of this experiment was to find optimal and simple parameters for fabrication of highly efficient solar cells with earth rich materials, which are capable of large scale deployment. Spray pyrolysis is a simple method for the creation of thin film solar cells. In this process, a solution is "atomized" into small droplets. Heated substrate evaporates the solvent, leaving behind a precipitated thin film. This technique was used to deposit a film of doped Fe_2O_3 onto a heated glass substrate, with a 100% ethanol solvent. The Fe_2O_3 was doped with Zn from $ZnCl_2$. The samples were then analyzed for optimal morphology/film quality, resistivity, and transmittance using a 4-point probe, scanning electron microscope, and spectrophotometry. There was found to be no correlation between morphology patterns of doped and un-doped samples with the same deposition parameters. The optimal doped film structure was found to be amorphous. Optimal doping was at 9%, with a resitivity of 450 Ω-cm.

Studying the Effect of Materials and Processing on the Electrical Properties of Bilayer Al/Amorphous CoTiN Metal Gates for Advanced Nanoelectronic Devices

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Amorphous metal gate stacks present several advantages over traditional polysilicon gate stacks. These include lower electrical resistivity, elimination of polysilicon depletion, and boron penetration effects. The recent utilization of amorphous metal gates has enhanced the electrical properties of complementary metal oxide semiconductor (CMOS)-integrated circuits by reducing work function and threshold voltage variability. Additionally, amorphous metal gates are expected to exhibit enhanced diffusion barrier properties, which would stabilize the work function by reducing intermixing of different metal layers. Due to their recent debut in semiconductor technology, however, amorphous gate mechanics have yet to be fully investigated. Consequently, understanding the effect of structure, materials, and processing on the electrical properties of transistors, and optimizing the gate stack remain a challenge. The goal of this project is to study such effects in a bilayer metal gate structure consisting of aluminum (Al) as an upper layer and either titanium nitride (TiN) or cobalt titanium nitride (CoTiN) as a bottom layer. In this work, we study the diffusion barrier properties of polycrystalline TiN and partially amorphous CoTiN gates by measuring capacitance-voltage characteristics and extracting their work function, which determines transistor threshold voltage. We will determine if the amorphous gates effectively resist Al diffusion while preventing threshold voltage fluctuation, properties essential to increasing operational speed and efficiency in industrial nanoelectronic devices.

Extent of Dopant Activation after Microwave and Rapid Thermal Anneals Using Similar Heating Profiles

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NNIN REU Mentors: Ms. Zhao Zhao, School of Engineering of Matter, Transport and Energy, Arizona State University; Dr. A. Lanz, Department of Mathematics, Norfolk State University
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Many sustainability issues arise during the current manufacturing processes used for semiconductor-based solar cells. Microwave (MW) heating could be adopted as sustainable since it is cheaper and more efficient than conventional furnace systems. In addition, microwave heating is directly produced inside the material. In this study, we compared the extent of dopant activation and damage repair for a MW anneal and a conventional rapid thermal anneal (RTA) with identical heating profiles. Sheet resistance measurements were used to assess the extent of dopant activation and ion channeling were used to monitor the extent of damage repair. The results showed that for identical heating profiles, MW annealing resulted in better dopant activation and damage repair.

Photovoltaic Devices Made from Plasma-Doped 2D Layered Semiconductors

Samuel Arthur
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Two-dimensional (2D) layered transition metal dichalcogenides (LTMDs, especially WSe_2 and MoS_2) exhibit a high absorption of visible lights. For example, a LTMD monolayer (~0.5 nm) can absorb as much sunlight as 50 nm thick Si films. Therefore, they are suitable for making next-generation ultrathin, flexible photovoltaic (PV) devices. However, society lacks the device physics knowledge and skills for generating built-in potentials in such emerging layered materials, which are required to separate photo-generated electron-hole pairs and create photocurrents. This REU project seeks to leverage the plasma-doping method and vertically stacked LTMD heterostructures developed by Liang's group to create and optimize PV devices made from multilayer WSe_2 films with plasma-doping-induced p-n junctions. To achieve this goal, we fabricated PV devices with a vertically stacked indium tin oxide (ITO)/WSe_2/Au structure, using 2D layer printing, photolithography, thin-film deposition/lift-off, and plasma etching/doping. In particular, F-contained plasma is used to dope F acceptors into WSe_2 layers to induce a p-n-junction built-in potential. Our results provide critical information for identifying the band diagram of WSe_2 PV devices as well as optimizing their PV performance. This work provides scientific insights of the unique optoelectronic properties of 2D LTMDs at the backbone of emerging atomically layered PV devices.

Conductive TiN Films

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Atomic layer deposition (ALD) conducting films are used in modern electronics due to their properties of low resistivity and ability to evenly coat high aspect ratios. ALD deposited titanium nitride (TiN) films are currently used as a metal gate material, a diffusion barrier for copper electronics, and as a metal electrode. In these applications, one limiting factor is the resistivity exhibited by the material. Lowering this resistivity would allow for improved functionality and help make way for more advanced devices. This can be accomplished by varying the parameters of the plasma step used in each ALD cycle. The project centered on the variation of these parameters to achieve lower resistivity.

The Effect of Low Temperature Growth and Annealing on the $Al_2O_3/In_{0.53}Ga_{0.47}As$ Interface

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Indium gallium arsenide ($In_{0.53}Ga_{0.47}As$) is the leading candidate for post-Si n-channel technology partially due to its low effective electron mass. Additionally, high-κ dielectrics, like Al_2O_3, grown by atomic layer deposition (ALD) are being explored as gate oxides to prevent current leakage while maintaining high capacitances. However, lattice mismatch and large surface defect concentrations on InGaAs lead to a high interface trap density (D_{it}) at the dielectric/InGaAs interface. Previous work has shown that *in situ* surface pretreatments using alternating cycles of nitrogen plasma and trimethylaluminum (N*/TMA) can successfully passivate the interface for a 300°C growth and 400°C furnace anneal. However, material limits make it desirable to modify this passivation technique for low temperature processing. This work explores the quality of the $Al_2O_3/In_{0.53}Ga_{0.47}As$ interface grown at 100°C by ALD and annealed below 250°C. Varying the annealing process found that a 250°C forming gas anneal, nearly independent of time, gave the best film and interface. Additionally nine cycles of N*/TMA was found as the optimum pretreatment giving a maximum midgap D_{it} of $6.85\pm0.37\times10^{12}$ $cm^{-2}eV^{-1}$. Though a higher quality dielectric film and dielectric/InGaAs interface are achieved at high temperature, these results show acceptable D_{it} and C-V behavior for use when low temperature processing is necessary.

Synthesis, Device Fabrication, and Characterization of Two-Dimensional Transition Metal Dichalcogenides

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Semiconducting two-dimensional transition metal dichalcogenides (TMDs), in particular molybdenum disulfide (MoS_2) and tungsten diselenide (WSe_2), have been the focus of intense research in recent years for their potential use in next-generation, scaled down electronic and optoelectronic devices due to their tunable direct bandgap as a monolayer and unique chemical, optical, and mechanical properties. This makes TMDs an excellent material candidate to replace silicon in conventional electronic devices such as field effect transistors, yet there still exists a need for optimized device fabrication and a scalable growth process for controllable large area, single-crystalline films. This project focused on three main objectives: the construction of a new metal organic chemical vapor deposition system for advanced material synthesis of MoS_2, WSe_2 device fabrication for Hall mobility measurements, and selective sidewall growth of graphene and WSe_2 on various patterned substrates. Van der Pauw devices were fabricated by photolithography, inductively coupled reactive-ion plasma etching, and metal thin film deposition by e-beam evaporation. Samples and devices were characterized by field emission scanning electron microscopy, profilometer, and Raman. Van der Pauw devices were fabricated on several WSe_2 samples of varying morphology. CVD growth of WSe_2 on Al_2O_3 was successful for shallower etch depths dependent on process conditions which will be explored further for future device research. The device measurements were unsuccessful due to lack of TMD coverage in the isolated channel regions, an issue that will hopefully be mitigated by elimination of powder precursors and the implementation of the new, scalable MOCVD system.

Optimization of Hybrid Fuel Cell Designs and Materials

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Hybrid fuel cells produce electricity by means of an electrochemical reaction and have the potential to produce quiet, efficient, and zero emissions energy without the need for a water management system. The hybrid fuel cells studied combine elements from a proton exchange membrane (PEM), which only conducts protons, and an anion exchange membrane (AEM), which only conducts hydroxides. The region between the AEM and PEM is very important and comparable to the p-n junction of a semiconductor diode or solar cell. There is a junction potential at the interface which contributes to the overall fuel cell voltage. The main focus of this research is on the interface material which is positioned between the PEM and AEM in the fuel cell. This region is important because it provides the adhesion between the AEM and PEM and water is created at this interface when the hydrogen ions and hydroxide ions combine. Two hybrid fuel cells were assembled with different interface materials. The interface material in fuel cell one was a polymer that interacts with protons and hydroxide ions. The interface material in fuel cell two was an ionic liquid which conducts only hydroxide ions. Electrochemical analyses, including voltammetry, impedance spectroscopy, and chronoamperometry were performed on both cells.

Atomic Layer Deposition of Tin Oxide

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Atomic layer deposition (ALD) is a technique that presents a plethora of opportunities in microelectronics and for producing high-quality, low-porosity conformal nanostructures. Tin dioxide, SnO_2, is to be deposited within the void space of a face centered cubic (FCC) silica opal lattice. SnO_2 is a viable metal oxide for the formation of inverse opals due to its stability when the silica spheres are etched away. Furthermore, its use as an effective interfacial layer for Ohmic contacts between a metal and semiconductor is being explored. SnO_2 is deposited by ALD using tetrakis (dimethyl amino) tin and water. The infiltrated 30-nm opals are etched with HF to remove the silica opal template. The resulting inverted SnO_2 opals will be characterized through field emission scanning electron microscopy (FE-SEM) and transmission electron microscopy (TEM) to explore its morphological and filling efficiency. In this work, we are filling opals that are smaller than have been previously studied. Applications for these nano-opals include gas sensors and lithium ion batteries.

Selective Area Atomic Layer Deposition: Developing Techniques that will Enable Single-nm Technologies

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Atomic layer deposition (ALD) is a chemical vapor deposition process with self-limiting growth, providing atomic level, or "digital," control of thickness. Selective deposition extends this precise control to three dimensions, so three-dimensional structures can be created without lithography. To deposit selectively, growth is promoted on one surface and prevented on another by varying deposition conditions as well as adding a "co-reactant." The adsorption of ALD precursors could be reversed on certain substrates, effectively preventing deposition. This project probes the use of dimethylamine (DMA) as the "co-reactant" with three precursors: pentakis-(dimethylamino)tantalum (PDMAT), tetrakis-(ethylmethylamino)hafnium (TEMAH) and tris(dimethylamino)silane (3DMAS). The nucleation of each precursor on a metal and dielectric substrate was studied. Saturation curves of film deposited vs. dose time were generated for PDMAT and TEMAH by exposing the substrates to the first half of an ALD cycle. For 3DMAS, thicker films were deposited and the growth rate was estimated using *ex situ* ellipsometry. *Ex situ* x-ray photoelectron spectroscopy (XPS) was used to determine amount of precursor deposited. Future work will repeat these experiments adding a co-exposure of DMA, and results will be compared with saturation curves generated this summer.

Graphene Growth by Chemical Vapor Deposition

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Graphene is a single layer of carbon atoms that is extremely strong, electrically conductive, transparent, and flexible. These properties lead it to have a variety of applications depending on how it is produced. Chemical vapor deposition, or CVD, is the preferred method of production to implement in touch screens, smart windows and solar cells. The focus of this project was to determine the ideal conditions in which to grow graphene via CVD. Based on success in previous graphene experiments, the two materials chosen to use in this project were copper and nickel. The samples were heated to 1000°C and both methane and hydrogen gasses were pumped through the system. Raman spectroscopy was used to characterize the samples, and it showed single-layer graphene on both nickel and copper. Through this, a range of conditions has been deduced where it is most probable that graphene will grow.

Aluminum Induced Crystallization of Amorphous Silicon on Patterned Substrates

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Aluminum-induced crystallization has become an attractive method of fabricating polycrystalline silicon on insulating substrates because of its ability to produce thin films with uniform surface orientations, and, its low process temperatures (<500°C) which makes the use of much cheaper substrates such as glass possible. By using patterned substrates to align the grains in the films we hope to minimize the presence of high angle grain boundaries which tend to act as defects and inhibit device performance. Previous studies on patterned substrates made with contact lithography and reactive ion etching showed increased crystallization rate in the patterned region, but the preferential orientation was lost. It was found that the patterned surfaces were significantly rougher than the unpatterned surfaces, which may have led to the loss of preferential orientation. This work examines the effect of surface roughness on crystallization rate and orientation. Samples with higher and lower patterned region surface roughness were prepared by using contact lithography and fluorine and chlorine-based plasma etches, respectively. Electron beam evaporation was used to deposit 30 nm Al and a-Si layers onto patterned substrates, and then AIC was performed by annealing the samples below the Al/Si eutectic temperature, at temperatures between 400 °C and 500 °C. *In situ* and post anneal optical microscopy were using to determine the effect of patterning and roughness on crystallization and grain size. X-ray diffraction and orientation imaging microscopy were used to determine the effect on crystal orientation. We expect that the smoother surface will be better able to preserve preferential crystal orientation while maintaining the increased crystal growth rate.

Optimization of High Growth Rate GaN Thin Film Mobility

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Gallium nitride (GaN) is a semiconductor of interest because of its current use in light-emitting diodes (LEDs)/ lasers and because of its potential future applications in high power and high frequency devices. One prominent GaN growing method is plasma-assisted molecular beam epitaxy (PAMBE). We explored how n-type GaN electron mobility is affected by PAMBE conditions, and the primary goal was to determine the conditions that produce the highest mobility. First, we performed a doping study to determine which carrier concentration produces the highest mobility. We then optimized mobility by varying plasma power and flow rate. All carrier concentrations and mobilities were determined using the Hall Effect. The doping study demonstrated that the optimal carrier concentration was ~ 1.5×10^{15} cm^{-3}. The highest mobility at this optimal carrier concentration was ~ 600 $cm^2/V{\cdot}s$.

Interlayer Dielectric and Interconnect for Heterointegration

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In order to vertically integrate heterogeneous electrical devices, compatible processes for interlayer dielectrics and metal interconnect are needed. The focus of this project was to study silicon dioxide (SiO_2) as an interlayer dielectric for heterointegration of two process technologies. The first steps of this process were to develop and characterize high quality PECVD SiO_2 film deposition by fabricating capacitors to test film electrical characteristics. Once the film was assessed to be viable for the desired application, via etch hole and metal interconnect technologies were developed and characterized to facilitate later integration of diverse devices. Initially, test structures were made to verify the electrical connection between the top contact layer of the bottom device and the bottom electrode layer of the top device. These test samples were followed by fabrication of the heterogeneously integrated devices. The ability to reliably integrate heterogeneous devices will enable new applications.

Nanoparticle Photoresists: Synthesis and Characterization of Next-Generation Patterning Materials

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Hybrid metal oxide nanoparticle photoresists are prominent candidates for next-generation photolithography due to their exceptional sensitivity to extreme ultraviolet (EUV) radiation. To improve the resist's resolution, roughness, and sensitivity (RLS) performance, we explore new compositions for this nanoparticle system. The allowed log dissociation constant (pKa) range for the functional ligands comprising the particle shell is approximately 3 to 5; in this region, the sensitivity of the resist positively correlates with the ligand's pKa. In this study, a series of nanoparticle resists in the pKa range are synthesized and characterized by solubility and radiation dose tests, as well as deep ultraviolet (DUV) and electron-beam patterning.

Decreasing Contact Resistivity to n-InGaAs with ALD TiN with TDMAT

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Contact resistance limits the further scaling of many electronic devices such as transistors. Next generation heterojunction bipolar transistors (HBT) not only require very low contact resistivities, but also very high current densities. Because these high current densities cause diffusion and electromigration in non-refractory materials, it is necessary to use a conductive material with high melting temperature, such as titanium nitride (TiN). Atomic layer deposition (ALD) of TiN allows for uniform coating of high aspect ratio structures (needed for contacts) necessary in RF devices and is thus advantageous over other deposition methods. In order to efficiently operate next generation HBTs, two properties of TiN must be improved: film resistivity and interface (contact) resistivity. The focus of this project is to improve both and thus enable the 64 nm emitter widths that are currently being developed for next generation HBTs. Multiple variables within the ALD process have been studied including plasma time, plasma power, and chamber pressure. The resulting technique is capable of reducing film resistivity by 4x when compared to the initial film and improving upon the lowest reported value to date. Recently, this newly developed TiN has been incorporated into HBTs for initial processing and testing.

Using Fluid Dynamics Modeling to Guide the Fabrication of Patterned Shearing Blades for the Solution Deposition of Single-Crystalline Organic Semiconductor Thin Films

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Organic semiconductors (OSCs) are promising materials for applications requiring flexible and transparent electronics and have the potential to be produced using low-cost solution processing methods. However, typical solution-based techniques create polycrystalline OSC thin films that have not been able to reach the performance of single crystals grown by vapor-based deposition methods. Our group has previously achieved the deposition of large OSC single-crystalline domains by a technique called solution shearing, in which a movable shearing blade passes at a fixed velocity across a substrate to coat it with an OSC solution. This process allows the solution to evaporate and deposit the OSC solute as a thin film. We have already shown that by patterning the shearing blades with micropillars—which induce recirculation in the OSC solution during shearing—we can deposit high-quality single-crystalline thin films with unprecedented performance in field-effect transistors. In this work, we use computational fluid dynamics simulations in COMSOL Multiphysics to model the effects of different pillar patterns on the solution flow during shearing. We fabricate these blades using photolithography to study their effects on films of 6,13-bis(triisopropylsilylethynyl)pentacene. This study will allow us to correlate simulated fluid flow with experimental blade performance, enabling the use of modeling for future blade development.

Patterning Silicon Nanowire Arrays using Electron-Beam Lithography

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Silicon nanowires have applications as advanced solar energy collectors, lithium ion anodes, catalysts and biological and chemical sensors. Silicon nanowires have demonstrated superior light absorbance in photovoltaic cells. The peak wavelength of light absorbed is tunable, depending on length, doping, spacing and diameter. Length and doping control in silicon nanowires are fairly well understood. The focus of this project is to develop a method for finely controlling diameter and spacing of silicon nanowires in an array and to transfer technology from ultra-high vacuum (UHV) to more scalable systems. Electron-beam lithography (EBL) was chosen because it can pattern samples with the nanometer resolution required. Using poly (methyl methacrylate) (PMMA) as electron-beam resist and electron-beam evaporation to deposit gold, an array of gold catalyst nanodots was developed on the silicon substrate surface. Then silicon nanowires were grown from each gold catalyst dot through vapor-liquid-solid deposition, in which silane decomposes on the catalyst surface, creating a liquid gold silicon eutectic, and a silicon crystal grows epitaxially on the bottom of the eutectic droplet. The goal is to create arrays of nanowires with diameters as small as 20 nm.

Effects of Adhesion Layers in Silver Plasmonic Nanoparticles for Surface-Enhanced Raman Spectroscopy (SERS)

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Surface-enhanced Raman spectroscopy (SERS) of plasmonic nanoparticles can be useful in biomedical practices including cancer detection because of these particles' low detection limits. Lasers at certain wavelengths excite localized plasmon resonances which enhance local electric fields and result in higher Raman intensities — this makes the particles easier to detect. Electron energy loss spectroscopy (EELS) spectra of these nanoparticles taken with a transmission electron microscope (TEM) have peaks at energies corresponding to plasmon resonances. Previous work with gold nanoparticles has shown that Raman wavelengths with energies corresponding to EELS energy peaks result in higher Raman enhancement. In addition, a titanium adhesion layer under the gold nanoparticles results in low intensity peaks in EELS spectra and no Raman enhancement. We fabricated silver plasmonic nanoparticles via electron beam lithography on silicon wafers with titanium and mercaptopropyltrimethoxysilane (MPTMS) adhesion layers. Raman spectra of the silver nanoparticles revealed no enhancement with titanium layers and high enhancement with MPTMS layers, agreeing with gold results. Plasmon peaks in silver EELS spectra did not align with enhancement as well as gold EELS spectra. Further investigation is needed to determine a correlation between large plasmon resonance peaks in EELS spectra and high SERS enhancement factors.

Growth and Transfer of Two-Dimensional Semiconductors and Heterostructures

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Physical vapor transport (PVT) was utilized to grow two-dimensional semiconductors that can be used in devices such as transistors, LEDs, and solar cells. Molybdenum diselenide ($MoSe_2$), which is in the transition metal dichalcogenide (TMDC) family, was the main semiconductor grown during this study. Although single layer $MoSe_2$ has been identified recently through exfoliation, the ability to consistently grow monolayer semiconductors would provide for a more time-efficient procedure that can be exercised for numerous applications. Despite the heavy advantages of growing monolayers, a limited number of papers have been released in which $MoSe_2$ monolayer crystals have been grown via PVT. In this study, $MoSe_2$ and other TMDC thin flakes are grown onto a SiO_2 on silicon substrate in a high-temperature furnace using PVT. Monolayer crystals were distinguished and characterized by optical imaging, photoluminescence measurements, and atomic force microscopy. By spin-coating polydimethylsiloxane (PDMS) onto the growth substrate, we were able to transfer the as-grown samples successfully. The PVT methods explored in this study can be further developed to create either lateral or vertical heterostructures between different monolayers.

Fabrication of Five-Terminal Laterally-Actuated Nano-Electro-Mechanical Relays for Ultra-Low Power Applications

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Nano-electro-mechanical (NEM) relays offer reliable alternative switching with low leakage current compared to MOSFETs. In a NEM relay, applying voltage to a gate electrode causes electrostatic force to mechanically actuate a beam, which makes contact between source and drain electrodes, allowing current to flow. One of the present drawbacks of NEM relays is that pull-in voltages at which switches actuate is extremely high (~20V). This project primarily focuses on researching all key parameters for fabricating laterally-actuated (in-plane) cantilevered NEM relays and investigates how these parameters at different fabrication steps affected the relays. First, polysilicon and silicon dioxide are grown on a silicon wafer, relay patterns are transferred to the substrate by electron-beam lithography (EBL). A layer of titanium nitride (TiN) is then deposited by atomic layer deposition (ALD), the contact area is patterned by a second EBL, and TiN is etched anisotropically. Finally, the beam is released from the surface of the wafer by etching with hydrofluoric acid. Parameters such as deposition temperatures and etch times are varied in an effort to produce a durable, lower pull-in voltage relay. These experiments serve as a solid basis for investigating low pull-in voltage NEM relays, a step towards integrating the devices into ultra-low-power applications such as computing.

A Coupled Dipole Approach to Electron Energy Gain Spectroscopy

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Electron energy gain spectroscopy (EEGS) is a spectroscopic technique designed to provide high-resolution imaging of metal nanoparticles and their collective electronic oscillations called plasmons. The EEGS procedure involves pumping a plasmon with a continuous or pulsed light source from a laser, passing a high-energy (~100 eV) electron beam generated within a scanning transmission electron microscope (STEM) near the nanoparticle, and observing the energy lost or gained by the electron as a result of its interaction with a plasmon. The primary directive of this project is to produce a numerical model of an EEGS experiment to simulate and predict the new spectral and spatial information content contained within it. This is done by extending a coupled dipole or discrete dipole approximation (DDA) method that assumes the target nanoparticle is composed of a large number of individual polarizable points driven by both a laser and a STEM. In my presentation I will discuss the methods by which this model is constructed and the implications of a functioning experimental simulation.

Nano- and Micro- Structural Characterization of Alternative Cement-Based Materials

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Globally, the cement industry accounts for approximately 5% of current anthropogenic carbon dioxide (CO_2) emissions. One method the cement industry has implemented to reduce CO_2 emissions is replacing a portion of cement clinker with filler material such as limestone. However, it is crucial to understand the effect of limestone addition on the hydration and microstructural development of cement. The focus of this present study is to (a) explore the complex hydration chemistry of various Portland limestone cements using a spectroscopic approach, (b) correlate relevant spectroscopic signatures to morphological information, and (c) analyze the chemical composition and porosity of the hydrated cement pastes. The cement hydration process was monitored using Raman spectroscopy, a relatively innovative technique in the field of cement study, and the formation of various cement hydration products was detected from one hour to several weeks of hydration. A comprehensive understanding of cement hydration was obtained by correlating relevant Raman spectroscopic signatures with morphological information determined by scanning electron microscopy and specific surface area analysis, chemical composition information provided by thermogravimetric analysis, and information on the reaction kinetics obtained by isothermal calorimetry.

Optimizing Mesoscopic Device Fabrication on Indium Arsenide/Gallium Antimonide Bilayers

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The main goal of the project is to improve gate control of group III-V semiconductors grown through molecular beam epitaxy. The semiconductor material focused on in this project included InAs/AlSb quantum wells and InAs/GaSb bilayers. Surface contamination and surface oxides on the heterostructures were noted to be a possible cause of hysteric gate operation. InAs/AlSb/GaSb heterostructures have electronic properties that make them useful for electronic and optoelectronic application, such as, quantum computing [1]. However, their implementation in electronic devices has been limited because of difficulties in fabricating devices which may result in leakage paths, hysteretic gates, and low gating efficiency. A possible solution to this could be passivation through atomic layer deposition and exposure to plasmas that can clean surfaces immediately prior to depositions [2]. Depositing atomic layers of aluminum nitride and aluminum oxide were both tested.

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Mechanical Properties of Hierarchical Nanoporous Metal for Flexible Batteries

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A lot of research focuses on fabrication of hierarchical nanoporous structure to apply to new devices. Also, polymer has attracted attention for the application of materials. We have reported that nanoporous gold (NPG) obtain by dealloying Au/Ag foil with HNO_3. Nanoporous copper fabricated by Cu/Si foam dealloying to use HF [1]. Furthermore, it is well known that self-organized winkle structures are the deformable anisotropic microstructure. Those wrinkle structures are can be obtained by difference of Young's modulus [2]. In this report, we show the preparation and measurement surface properties of the heterostructure by combining metal foam and polymer. We fabricated three different samples; NPG on polydimethylsiloxane (PDMS), nanoporous copper on PDMS, and nanoporous copper on silicon wafer. Metal foams were obtained on PDMS by sputtering, and after that, dealloying samples. As a result, metal foam and polymer heterostructures were obtained. The surface basic properties of the sample will be discussed.

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Characterization and Modelling of Carrier Dynamics in Thin Films of GaN

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Hall mobility and carrier concentration measurements provide an analysis technique for measuring gallium nitride (GaN) film quality. Because mobility is characterized by carriers reacting to different scattering events, it provides a means for determining defect concentration which would otherwise be difficult to measure. The mobility, and thus the defect concentration, can be used as a means of comparison between samples of varied GaN growth conditions. To obtain the defect concentration we created software to perform data fitting of temperature, carrier concentration, and mobility data taken from variable temperature Hall measurements. This data is fitted to the charge balance and mobility equations allowing for the calculation of donor concentration, acceptor concentration, apparent donor binding energy, and occupancy of traps along a dislocation. These values were then used to plot the mobility due to six scattering mechanisms along with total fitted mobility. From this, dominant scattering mechanisms for various growth conditions can be observed. The four calculated parameters previously mentioned along with mobility values provide a context for a comparison of samples grown with varying growth conditions.

Bio-Inspired Surface Treatments and Quasi-Ordered Nanostructures to Control Broadband IR Response

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Moth-eye nanostructures have been fabricated on silicon using colloidal lithography and reactive ion etching for enhanced optical transmission in the near to far infrared wavelength range (λ=2-50μm). However, in previous reports, despite having high transmission, the nanostructures produced were fragile and were fabricated in a two-step process which was time consuming, complicated, and difficult to control. Here, we demonstrate the fabrication of similar, yet more robust, high transmission nanostructures on silicon by systematic modification of etch parameters which include gas flow rates ($SF_6/C_4F_8/Ar$), RF power, and etch time for a simplified single-step vertical etch. Using this method, the fabrication of moth eye nanostructures on germanium was also demonstrated. Nanostructures were characterized via Fourier transform infrared spectroscopy for total transmission, direct transmission, specular reflection, and diffuse reflection measurements. High transmission was observed on both materials for both single-sided (Si: ~94% of theoretical limit, Ge: ~97% of theoretical limit) and double-sided (Si: ~88% of theoretical limit, Ge: ~92% of theoretical limit) nanostructured substrates.

Developing Micropatterns for the Investigation of Heart Cell Function

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Polydimethylsiloxane (PDMS) is a silicone based polymer that can serve as a flexible substrate for cell culture. The goal of this project was to microfabricate PDMS structures to study contractile forces and intracellular organization of living mutant and healthy cells. Mutations in lamin proteins, which line the cell nucleus, cause approximately 10% of inherited cases of dilated cardiomyopathy, a disease responsible for a third of all heart failures. By comparing lamin mutant and healthy cells, we can develop a better understanding of how the mutations affect cellular function, gain new insights into the origin of the disease, and identify potential treatment approaches. We utilized soft lithography techniques to create SU-8 micropillars from which a PDMS mold was cast to create thin, flexible PDMS micropillars for contractile force assessment of cardiac cells. In addition, we used PDMS devices containing equally spaced lines to assess the organization of cells and their cytoskeleton grown on lined substrates. These two microfabricated devices, pillars and lined substrates, were tested with human fibroblast cells and high-speed video microscopy. Future work for this project includes the observation of the PDMS devices with heart cells differentiated from stem cells and measuring deflection of the pillars to exactly quantify the contractile forces of the cells.

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

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Polydimethylsiloxane (PDMS)-based microfluidic devices provide a well-known *lab-on-a-chip* technique that affords rapid prototyping and an efficient platform for drug screening. We use such devices to generate *water-in-oil* emulsion droplets at high throughput that efficiently encapsulates cells in presence of drugs. The emulsion provides millions of individual reaction compartments for *in vivo* drug screening assays at different physiologically relevant concentrations. Reducing the size of the reaction compartments to sub-nanoliter volumes allows us to be parsimonious with reagents while the large numbers of droplets provide superior statistical resolution. In this work, we design, fabricate and use microfluidic devices to test the efficacy of anti-cancer drugs using a human cancer cell line (lymphoblasts) where the drug concentration is systematically varied. The efficacy of the drugs is measured as functions of exposure time and concentration from the cell-fate of the lymphoblast cells in each drop in their presence, using commercially available fluorescent reporter kits.

Sphingosine 1-Phosphate Functionalized Nanopatterned Scaffolds for Engineering Vascularized Skeletal Muscle Tissue

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Duchenne muscle dystrophy (DMD) is a genetic disorder that affects 1 in 3600 males, leading to early death due to a lack of dystrophin in muscle tissue. Implanted primary muscle cell patches have previously been shown to increase myogenesis and dystrophin expression in DMD mouse models [1]. This project involves cultivating muscle cells on biomimetic nanopatterned biodegradable poly(lactic-co-glycolic acid) (PLGA) scaffolds that are fabricated using capillary force lithography. These scaffolds mimic topographical cues presented by the aligned collagen fibers of the extracellular microenvironment in skeletal muscle. Sphingosine 1-phosphate (S1P) is a circulating lipid metabolite known to promote angiogenesis, myoblast differentiation and satellite cell proliferation. By functionalizing the nanopatterned scaffolds with S1P, we hypothesize that the muscle tissue will be more mature and vascularized prior to implantation, therefore integrating better with the host tissue to ultimately improve function in dystrophic muscles. The optimum concentration of S1P will be determined using data on cell adhesion/viability, immunostaining for endothelial and myogenic markers, and qRT-PCR regarding myogenic, endothelial and neurogenic genes.

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Disruption and Control of Microbial Biofilm Growth

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Microbial biofilms of the species *Bacillus Subtilis* have been grown so that the changes in the expression of several important phenotypes can be analyzed using fluorescence microscopy. Biofilms exist in all kinds of environments; instead of acting as independent swimmers, the cells work as a community, which in turn results in a number of benefits for the colony, making it the preferred living condition for bacteria. However, the ability of biofilms to survive in harsh environments can cause serious problems in the medical and industrial fields where they lead to the spread of infection and degradation of components. Understanding the factors that lead the bacteria to change from one phenotype to another can provide insight to the best approach in solving these issues. We have performed a set of novel experiments where the bacteria are presented with physical barriers that interrupt the normal expansion of the colony across the surface of the agar substrate. The barriers have led to a unique response from the bacteria in respect to the growth rate along certain areas as well as the expression of a certain phenotype in a specific location. A future set of experiments are considered to prove the validity of the proposed mechanisms explaining these observations.

Microfabrication and Dynamic Testing of Electromagnetic Microactuators for Endomicroscopy

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Current endoscopic imaging, while sufficient for detecting gastrointestinal polyps, is unable to see below the tissue surface where carcinoma can form. Unlike conventional white light endoscopy, which is limited to horizontal (XY) cross-sectional imaging, more advanced endoscopy tools such as dual-axes confocal and two-photon microendoscopes contain z-displacement scanning actuators that perform rapid optical sectioning and permit vertical (XZ) cross-sectional images of tissue. Consequently, how far these endomicroscopes can see into the tissue is limited by how much z-displacement actuation can be achieved in small diameter (3-5mm) endoscopes. In this work, we fabricated electromagnetic z-displacement microactuators, which was done by characterizing the electroplating parameters of permalloy (20% Fe, 80% Ni), a material that exhibits strong magnetic properties. If large z-displacement is achieved, electromagnetic microactuators could prove an attractive alternative to current piezoelectric, electrostatic and thermal microactuators, which are complicated to assemble due to electrical connection requirements and require high voltages. First generation microactuators were successfully created and are currently under dynamic testing using a laser doppler vibrometer to determine their z-displacement at resonance. Second generation microactuators were then designed and fabricated with the objective to exhibit greater z-displacement by using silicon dioxide as the material for the bending beams in the microactuators.

Opto-Electronic Characterization of Narrow Band Gap Semiconductors at Cryogenic Temperatures

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Semiconductors are fundamental to modern technology, with uses ranging from scientific research to commercial applications in computing and telecommunications. There is a great deal of interest in studying these materials, both to improve their use in current technologies and to discover potential future applications in novel devices. In this project we work with a characterization apparatus used for studying semiconductors. This apparatus, consisting of a solid state 532 nm Nd:YAG laser, optical filters, fiber optic cables, a 10 K cryostat, and a monochromator, provides a photoluminescence spectrum of the studied material. The spectrum can then be used to determine the material's band gap, an important physical property. This work focuses on modifying the characterization setup to add the functionality of detecting semiconductors with narrow band gaps and measuring their electrical properties. These modifications include optimizing the arrangement of the setup's optical components, incorporating new components into the setup, and redesigning parts for the cryostat and monochromator using CAD software. The upgraded setup can both optically detect a wider range of semiconductors and electronically measure the semiconductors' properties. Preliminary photoluminescence studies were conducted on InGaAs samples with a peak emission wavelength of 1588 nm at room temperature.

Fabrication of Low-Density Vertically Aligned CNT Forests

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Carbon nanotubes (CNT) consist of one or several graphene sheets rolled into tubes. CNT attracts increasing attention because of their noticeable characteristics such as high electrical and thermal conductivities. Furthermore, the effect of growth conditions on the morphology of the CNT has been investigated for the co-relation of morphology and properties. The morphology of the CNT growth is sensitive to growth surface, catalyst stack and growth condition. Hence, the necessary factors involved in the CNT growth are the property of the catalyst, the deposition time and the growth condition including the existence of plasma and the flow of gas. In the present work, the effect of above experimental conditions on the morphology of the CNT growth was studied. We demonstrated the CNT growth on Fe or Ni catalyst layer using chemical vapor deposition (CVD). As a result, the growth and morphology of CNT was varied by different conditions and the dependence of some parameters on the CNT growth was indicated. Further, we plan infiltrated low density CNT forests with curable resin for the design and fabrication of CNT based robust electronic devices such as diode array.

A Tri-Axial Angular Accelerometer for the Vestibular Prostheses

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A tri-axial capacitive angular accelerometer is proposed and designed in 40 μm thick silicon-on-insulator (SOI) substrate. Vestibular prostheses are demanded by some individuals due to vestibular disorders that often cannot be treated using existing approaches. A vestibular prosthesis encodes angular head motion into neural activation profiles thereby conveying a sense of head motion. For a vestibular prosthesis application, inertial sensors are required but also must consume little power in order to reduce battery size and extent battery life. Recently, gyroscopes are widely used for angular motion detection because of their high sensitivity. From the perspective of reducing power consumption, however, angular accelerometers are preferred for vestibular prostheses. This project focused on developing a tri-axial angular accelerometer for vestibular prostheses. To detect angular acceleration in three planes, we proposed two types of sensor. Thanks to utilizing handle layer as bottom electrodes of differential capacitors, this design can be fabricated by one mask process. Devices were designed and simulated in COMSOL. The x and y axis sensors are 1.7 mm × 1.7 mm per sensor, and the z-axis sensor is 2.1 mm × 2.1 mm. Calculated sensors sensitivity are 2.64×10^{-16}F/r/s^2 (x, y axis) and 2.48×10^{-16} F/r/s^2 (z axis) with ± 2392 r/s^2 maximum detectable signal (x, y axis) and ± 4059 r/s^2 (z axis).

Growth of Boron Nitride for Two-Dimensional Applications

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Boron nitride (BN) is an isoelectronic compound similar to carbon that is sometimes referred to as white graphene. It has several applications due to its great chemical and thermal stability. Because of the weak Van der Waals forces between it's layers, it is a self lubricant which makes it preferable to graphene for certain applications, including but not limited to space applications. The main goal of this project was to grow BN on thin substrates using a horizontal chemical vapor deposition (CVD) system under high temperatures and pressures. Using diborane (B_2H_6) and ammonia (NH_3) as the precursors, several attempts were made to grow BN on sapphire (Al_2O_3), silicon dioxide (SiO_2), and silicon (Si). Also nickel surfaces of 150 A on silicon dioxide and silicon was employed. After growth, these samples were characterized using Raman spectroscopy, atomic force microscopy (AFM), and scanning electron microscopy (SEM).

Device Integration of Lithium Niobate Microring Resonators Patterned with a Silicon Hard Mask

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Lithium niobate (LN) is a promising candidate for integrated optical devices due to its combination of strong electro-optical and nonlinear optical properties. Ring resonators made of LN reduce device size and allow for nonlinear applications such as optical storage, second harmonic generation, telecommunication, and sensors. This project highlights work done to address two significant issues, the first dealing with the fabrication process non-uniformities and roughness and the second with device integration. A silicon layer was chosen as a hard mask because it can be deposited at high thicknesses, and the improved selectivity and hardness allows for the fabrication of a thicker LN structure. The device coupling efficiency, which is essential in nonlinear optics experiments, may be enhanced by improving the coupling between the waveguide and fiber. For this application, SU-8 waveguides were overlaid on the sample and attached to the existing waveguides to act as coupling pads for a lensed fiber. Cross section polishing is performed on the cleavage of SU-8 pads to minimize coupling loss. These methods described above will make the fabrication and optical test of LN devices more robust and increase the device performance by improving modal confinement and tunability.

Bi-Metallic Nanocrystals and Their Optical Properties

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The focus of this project is to study the properties of silver (Ag) nanocubes and create a Ag-Pd bimetallic nanocrystal with improved properties that monometals don't have. Ag nanocubes alone exhibit good surface-enhanced Raman scattering (SERS) properties, but Ag nanocubes show limited catalytic activities towards chemical reactions. On the other hand, palladium (Pd) is regarded as an important catalyst for many industrial applications but its SERS performance is poor. In order to combine SERS and catalytic properties in a single nanostructure, we try to deposit palladium atoms onto the corners or surfaces of the Ag nanocubes to generate Ag-Pd bimetallic nanostructures with different morphologies. By titrating Na_2PdCl_4 into growth solution composed of Ag nanocubes, PVP and ascorbic acid (AA), Ag-Pd core-frame nanostructures were obtained. We were also be able to get Ag-Pd hollow nanoboxes through etching the Ag-Pd bimetallic structures by H_2O_2. These hollow nano structures are more stable than Ag nanocubes, making them more ideal for SERS. The enlarged surface area should also be beneficial to their catalytic activities.

Microfluidic Bio-Sensing for *in vitro* Tumor Cell Proliferation

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Currently, chemotherapy drug testing on cultured cells is a time-consuming, tedious process. Varying doses of the drug are added to cultured cells, and cells are monitored for viability (percent of the culture flask is covered in cells). To accomplish this, researchers remove cells from an incubator (causing their local temperature, humidity and pH to drop), use a microscope to examine a small area of the flask visually (prone to error from non-uniform distribution), and return the cells to the incubator. Commonly, the cells are examined once a day for eight days. We present the fabrication of a monitoring system that allows for continuous-time, autonomous monitoring of cells inside an incubator. The system consists of a custom cell-monitoring device, a remote gate ion sensitive field effect transistor (ISFET), an amplifier, and a BeagleBone platform. The design, fabrication, and operation of the remote gate ISFET is described. We also describe how the ISFET was used to create the autonomous, continuous-time cell monitoring system. The system can monitor multiple cell populations, and it can be programmed for any interval (days in our case) or sampling rate only limited by the data storage. Finally, we present the results of monitoring cells dosed with a chemotherapy drug.

Surface Micromachining of Microfluidic Devices

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Microfluidic devices made of the silicone-based polymer polydimethylsiloxane (PDMS) are currently limited to soft lithography fabrication methods. Therefore, the engineering potential is restricted to structures such as wells, chambers, and valves (i.e., horizontal features). Through-holes, suspended beams, and other vertically sound structures would enhance the field of microfluidics, to the benefit of biomedical engineering. These vertical structures are needed to advance the overall complexity of microfluidic devices by introducing features such as filtration membranes or pressure gauges. The focus of this project is to apply new surface micromachining techniques for microfluidics. Photolithography was used to pattern the silicone-based polymer while two dry etch methods were explored in order to complete the fabrication process of these novel structures.

Design and Fabrication of a Microfluidic Device to Study Tumor Cell Mechanics During Metastasis

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The majority of deaths caused by cancer do not result from the primary tumor, but rather secondary tumors formed by metastasis. During metastasis, a tumor cell migrates through narrow gaps that are smaller than the size of the cell, such as in the dense extracellular matrix and blood capillaries. The deformed morphology and behavior that facilitate tumor cell movement through these paths is not well understood. In addition, conventional techniques to study cell mechanics, such as micropipette aspiration, require specialized equipment and training and are incapable of simulating the in vivo environment of a cell. To provide a more accessible and effective method for exploring the role of tumor cell deformability in metastasis, a multilayered polydimethylsiloxane (PDMS) microfluidic device was designed and fabricated using soft lithography to contain narrow paths that mimic the small vessels through which tumor cells metastasize. Specifically, the device has 16 channels with arrays of micropillars at the end of each channel to create gaps ranging from 6 to 10 μm. Moreover, a valve feature was incorporated in the design to control the flow through each channel and allow cells to flow through one array at a time. Using human breast cancer cell line MDA-MB-231, the valve feature was shown to successfully control flow through the channels. At the arrays, these cells' movement was restricted at the smaller gaps and required a larger flow rate in order to reach the deformed morphological state that would enable passage. Our results demonstrate that microfluidic technology offers attractive features that can be taken advantage of in order to develop a complex model of tumor cells.

The Interaction of Cytotoxins with a Lipid Membrane Library

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Cytotoxins are agents toxic to cells. To infect, cytotoxins must overcome the cell membrane, the primary defense of the cell. Membranes, however, are highly heterogeneous, containing many distinct domains differing by lipid content. For most cytotoxins, it is unknown if individual species differentiate between lipid compositions or if some domains act as nucleation sites for aggregation. Using microfluidic techniques, we have studied the binding affinity of inert Amyloid-Beta 40 and toxic Amyloid-Beta 42, a primary suspect that exhibits neurotoxic activity leading to Alzheimer's dementia, and the membrane binding portion of the Anthrax toxin, to a variety of lipid domains. By introducing the cytotoxins to a lipid domain library we were able to examine binding propensities, both individually and aggregated, to certain lipid rafts. We find that the binding of cytotoxins to lipid domains is a selective process.

Microfabricated Cell Array Device for Screening of Metastatic Potential

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Metastasis is a complex cell migration process where a cancer cell leaves its primary tumor site to establish a secondary tumor site, causing greater than 90% of cancer related deaths. One way to quantify the cell migration process has been to track single cells plated on a dish. However, this method is low-throughput and requires costly live microscopy chambers. Here we develop a high-throughput cell migration assay by employing microfabrication techniques to develop a method to capture single cells and place them in an organized array. We quantify cell migratory behavior by quantifying the disorder of the initial organized array. Migration of cancerous cells depends on the interactions between the cells and their microenvironments. Thus we validate our device by characterizing the migration of cells on substrates of varying stiffness. Upon completion of this project, the device will be usable as a diagnostic tool for rapid high-throughput analysis of metastatic potential of biopsied tumor cells.

Integration of Highly Porous Membranes with Microfluidic Body-on-a-Chip Devices

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In the research field of "Body-on-a-chip", the human body is scaled down and represented on a silicon or polymer chip. The chip is used to conduct experiments in which the efficacy and safety of new drugs is tested in an inexpensive way and without the need of animal experiments. Here, we aimed to include barrier tissues such as the gastrointestinal tract and lung epithelium with other human organs on chip. These tissues are important to simulate the uptake and bioavailability of drugs. We fabricated highly porous and robust membranes on which epithelial cells can be cultured within body-on-a-chip devices. We also fabricated the polymer chips and the corresponding housing for the devices. Finally, we conducted experiments with Caco-2 cells (gastrointestinal epithelial cells) and found that the device supports the culture of these cells, providing physical stimulation through fluidic flow and enough oxygen to support cell function. The developed model will be used to test the bioavailability of nano-scale drug carriers.

Functionalization of 6H Highly Doped Silicon Carbide Surfaces for Cell Electrophysiology

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Understanding the electrical activity of biological cells and tissue is important for medical diagnostics and bioengineering. Electrophysiology is employed to measure the electrical behavior of biological materials ranging in size from single ion channel proteins to entire organs. In order to measure the electrical properties of cells, they must be attached to a surface that is conductive and biocompatible. Silicon carbide (SiC) was used in this study because in addition to having these properties, its surface can be functionalized for protein attachment thus rendering the surface amiable for cell attachment. SiC was exposed to oxygen plasma to render OH groups on its Si face. The terminal OH groups were covalently bonded to 3-aminopropyltriethoxysilane (APTES). Raman spectroscopy measurements confirmed peaks for SiC and both oxidized and APTES functionalized SiC. The addition of APTES to SiC provided a reactive surface ready for antibody attachment and capable of supporting an antibody antigen reaction.

Label-Free Detection of *Escherichia coli* using Silicon Nanophotonic Biosensors

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Medical diagnostics influence 60-70% of treatment decisions. Yet sophisticated, sensitive diagnostics are still confined to hospitals and laboratories, limiting their impact in point of care settings. The growing field of silicon nanophotonic biosensors has the potential to bring clinically relevant and sensitive medical diagnostic capabilities to the patient bedside. These silicon-based sensors, which are compatible with today's established complementary metal-oxide-semiconductor (CMOS) foundry processes for high-volume, low-cost fabrication, utilize light to detect biomolecular interactions. However, while silicon photonics have been extensively investigated for small molecule detection, little has been done to assess their capacity for the interrogation of whole cells, including the bacterium *Escherichia coli*. The goal of this project is to demonstrate the potential application of silicon photonic sensors to bacterial detection and compare their performance to that of a competitive technology, namely surface plasmon resonance (SPR). We first verified and optimized binding of *E. coli* with SPR, developing an assay suitable for use on two different silicon photonic systems (ring and disk resonators). The results were compared to show the viability of bacterial detection using silicon photonic biosensors, and binding was characterized with scanning electron microscopy (SEM).

A Piezoelectric Material P(VDF-TrFE) Thin-Film Process Flow for Ultrasonic Transducers

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Thin-film high-frequency ultrasonic transducers are a good candidate for generating high frequency ultrasound into various materials. The time-of-arrival, dispersion, amplitude, and phase, of transmitted and reflected wave pulses can be used to characterize materials such as biological tissue. Piezoelectric polymer transducers are attractive in interrogating biological materials because of the good acoustic impedance matching, leading to low voltage drive and higher bandwidth. For these reasons, we developed a microfabrication process for P(VDF-TrFE) based ultrasonic transducer. The low acoustic impedance of the semi-crystalline copolymer (4.32 MRayls), allows for a better acoustic impedance matching to tissue/water (1.5 MRayls), resulting in increased coupling efficiency. All materials used in this process are complementary metal oxide semiconductor (CMOS)-compatible, which allows for fabrication of transducers directly on top of CMOS, greatly improving system complexity and integration. Layers in this process were defined using standard contact lithography. Aluminum electrodes were evaporated onto substrate, and defined by wet etching. The P(VDF-TrFE) thin film was deposited by spin coating, and defined by dry oxygen plasma etch. In situ electrical poling method was performed to induce piezoelectricity on the PVDF-TrFE films. The ultrasonic transducers fabricated by this process showed ultrasonic pulse transmission within the frequency range of 400-600 MHz. Signals with amplitudes of 2 Vpp resulted in receive signal amplitudes of 50 mVpp.

Cerium Doped Terbium Iron Garnet for Magneto-Optical Applications

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Thin films of magneto-optical materials are useful in optical isolators, which are devices used in photonic circuits as "optical diodes" to prevent reflected light from damaging the laser source. This is achieved by an effect called Faraday Rotation, which is a rotation of the polarization of light when passing through a magneto-optic material. The material studied in this project was cerium doped terbium iron garnet (Ce:TIG/$Ce_xTb_{3-x}Fe_5O_{12}$). The thin films were deposited on silicon and fused quartz substrates using reactive sputtering in an oxygen environment, while varying the cerium concentration. The samples were annealed at 700°, 800°, and 900° Celsius using the rapid thermal annealer (RTA). The characterization of the samples included measuring the Faraday Rotation using an optics bench setup with a 1545 nm laser, and correlation between increasing Cerium content and the Faraday Rotation coefficient was observed. Future work will include developing optical isolators from Ce:TIG for use in photonic circuits.

Characterization and Solar Cell Application of Gallium Antimonide Quantum Dots

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Intermediate band solar cells (IBSC) can potentially overcome the Shockley-Queisser conversion efficiency limit of photovoltaic devices. In addition to photocurrent generated by photons above the band gap, IBSC can utilize a "two-step" photocurrent, wherein sub-bandgap photons excite carriers from the valence band to intermediate band, then intermediate band to conduction band. Quantum dots (QDs) are one method of realizing intermediate energy states within the band gap. GaSb/GaAs QDs have type II band alignment, which is more suitable for solar cell application because of lower recombination compared to commonly used type I structures. By changing the GaAs barrier to AlGaAs we can achieve transition energies nearly matching the proposed ideal IBSC configuration for highest efficiency. We grew GaSb/AlGaAs QDs using molecular beam epitaxy. IBSC fabrication included photolithography, sputtering, and chemical etching. Optical characterization revealed that GaSb QDs in AlGaAs also have type II band alignment. Current-Voltage Characteristics showed that carriers are deeply confined in QDs. Two-step photocurrent in IBSC with GaSb/AlGaAs QDs was observed. Our results indicate that GaSb/AlGaAs QDs will provide ideal IBSC and deepen the understanding of the fundamental physics.

Regulation of the Immune System by DNA-Drug Nanomaterials

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Single stranded cytosine-phosphate-guanine ogliodeoxynucleotides (ssCpG ODN) have been shown to bind to Toll-like Receptor 9 (TLR9) located in the endosome of macrophage cells in the immune system. This allows for regulation of both the innate and adaptive immune system that can lead to medical treatments such as cancer immunotherapy. Double stranded non-CpG ODN (ds-nonCpG ODN) are capable of regulating the innate immune system through interactions with cytosolic receptors. Our goal for this project was to investigate how the shape of different nanomaterials can affect the transport of the ODN drug into macrophage cells. Both ssCpG ODN and ds-nonCpG ODN were functionalized separately onto a cationic lipid DOTAP, carbon nanohorn (CNH), polyethyleneimide-coated CNH, and MoS_2 monolayer sheet. The ODN-nanomaterial solutions were incubated in macrophage cells overnight and the RNA was isolated. Finally, reverse transcription and real time polymerase chain reaction were performed to measure the relative expression level of Interleukin 6 (IL-6) and Interferon beta (IFN-b), two proteins secreted in the adaptive and innate immune system pathways respectively. It was found that for both ssCpG ODN and ds-nonCPG ODN, samples incubated with DOTAP had the highest level of expression IL-6 and IFN-b.

Characterization of Ionic Liquid Gels used with Conformable Conducting Polymer and Textile Electrodes used for Electrophysiological Recordings

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One way to improve biosignal readings for electroencephalography (EEG) and electrocardiography (ECG) measurements is to improve the interface between the electrode and skin. Previously, a new gold (Au) electrode on a flexible Kapton substrate has been developed using a conducting poly(3,4-ethylenedioxythiophene):poly(styrenesul fonate) (PEDOT:PSS) polymer and ionic liquid (IL) gel. While the creation of IL gels, acting as a conductor between the electrode and skin, has helped to increase recording times and lower interface impedance, further improvement is still required to achieve long lasting measurements. Variances in multiple IL gel parameters such as formula, electrode deposition, and gel geometry were characterized to help produce, in total, a greater quality electrode. Impedance tests over a range of frequencies were used to determine the merit of each change in parameter. It was shown that increasing IL gel volume steadily decreased electrode impedance, instead of specifically thickness or surface area. While adhesive IL gels show a significant decrease in impedance when drop casted directly on electrodes as compared to an external IL gel mold, they exhibit less conductivity than the standard IL gel formula. Due to mechanical constraints at the interface of Au and the PEDOT:PSS polymer, a new deposition technique was also developed to improve durability.

Fabrication and Characterization of Diamond Field-Effect Transistors (FETs)

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The next generation of communication technology requires materials that can handle higher frequency and higher power. Diamond's excellent physical properties, such as high band-gap, high breakdown field, and the highest thermal conductivity of all materials, make it ideal for communication applications, and improving diamond field-effect transistor (FET) performance will make diamond viable for such applications. We fabricated and characterized hydrogen-terminated diamond (H-diamond) FETs with an Al_2O_3 gate insulator using laser lithography, e-beam lithography, ozonolysis, e-gun sputtering, atomic layer deposition, microscopy, annealing, and FET device analysis. Challenges of this process include improving the process yield and the drain current. We found that the high stability of the H-diamond surface causing the metal electrodes to easily peel off the surface, causing a low process yield, and we found that a poor interface between the gate insulator and H-diamond surface caused low drain current. Optimization of the fabrication process and annealing improved the process yield and the drain current, respectively.

A Microfluidic Approach to Stiffness Gradient Generation in Polyacrylamide-Based Cell Migration Analysis Platforms

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Collective cell migration is a critical component of many physiological and pathological processes. Understanding the role of extracellular factors affecting collective migration is necessary for developmental, metastatic, and wound healing pathways to be mimicked *in vitro*, and better regulated *in vivo*. Substrate compliance is one such factor that has been extensively studied in the scope of single-cell migration, often with a polyacrylamide (PAA) platform. Our approach for investigating the role of elastic moduli in collective cell motility uses a microfluidic system in which a PAA platform with a linear stiffness gradient is fabricated via photopolymerization. Compliance gradient ranges may be altered to physiologically-relevant values via changes in monomer and cross-linking agent concentrations. While similar devices have been used for migration study of single-cell motility, the substrate is made appropriate for collective motility study with surface functionalization via Poly-D-Lysine and photocleavable poly(ethylene glycol). This method involves cell micropatterning to control initial cell adhesion geometry and initiation of cell migration. Our techniques of substrate formation and functionalization result inplatforms with physiologically-relevant stiffness gradients and capability for light-driven alteration of cell adhesion for sophisticated motility analysis. These materials fabricated in the methods discussed offer a precise and dynamic platform for investigation of microenvironment compliance as a factor affecting collective cell-motility, and cell behavior, in general.

Development of Zeolite-Based Nanofibers to use in a Wearable Device for Uremic Toxin Removal in Kidney Failure Patients

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Kidney failure patients in disaster areas and developing countries face the danger of having conventional hemodialysis treatments become inaccessible due to limited resources. For this reason, our goal is to develop a wearable device consisting of polymer fibers with a smart material that will selectively adsorb uremic toxins from the bloodstream, effectively eliminating the need for more expensive treatments. The nanofibers contain the blood compatible poly(ethylene-co-vinyl alcohol) (EVOH) as the main polymer, embedded with zeolites, a porous aluminosilicate that has the capacity to absorb toxins such as creatinine. The polymer and the zeolites were characterized separately to determine the ideal combination for the polymer meshes. This ideal combination was found to be 9w/v% polymer fibers with a 10wt% ratio of 940HOA zeolites. This fiber was found to absorb an average of 5.23 mg of creatinine per gram of fiber solution, meaning the zeolite adsorption was an impressive 54.15 mg of creatinine per gram of zeolite in the fiber. It was unusual and unexpected for the nanofiber to have a higher per gram adsorption than the free zeolites, and so further studies will be performed. These results suggest that these nanofibers could substitute specialized equipment in removal of waste product from the bloodstream.

Effects of Gold Nanoparticle Size and Functional Group on Adipogenesis of Mesenchymal Stem Cells

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Mesenchymal stem cells (MSCs) are extremely useful in generating a multitude of cell lineages for tissue regeneration applications. The microenvironment of these MSCs is critical in regulating their differentiation, including soluble factors that bind to various cell receptors. Meanwhile, gold nanoparticles (AuNPs) have gained momentum in biological research due to their low cytotoxicity and ability to interact with biomolecules. Thus, the objective of this research is to examine the effects of AuNP size and functional group on the adipogenic differentiation of MSCs. In the first part of this project, AuNPs of two distinct sizes and ligands were synthesized and characterized. In the second part, these AuNPs were then added to MSC cell cultures. Cell growth, morphology, and adipogenic differentiation were examined. Cell number data indicated that large AuNP functionalized with β-mercaptopropionic acid inhibited cell growth, while optical microscope images appeared to show higher AuNP uptake when citrate was the ligand. ALP activity and Oil Red-O assays revealed that larger AuNP and AuNP functionalized with β-mercaptopropionic acid increased adipogenic differentiation in MSCs. Results indicate interesting biological implications of these β-mercaptopropionic acid on the AuNP surface, prompting exploration of the mechanism of interaction with the cells.

Investigation of Straight-Edge Graphene Grown via Segregation on Ni(110) using Scanning Tunneling Microscopy

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Controlling the size and shape of graphene grown on metal surfaces is key to the utilization of graphene in future applications. Despite having three-fold symmetry, graphene was found to grow in square shapes and with straight edges on the Ni(110) surface. This focus of this project is to clarify the growth mechanism of graphene on the Ni(110) surface by observing the edges of the graphene with atomic resolution. Graphene was first grown via the segregation method by heating and then cooling a carbon-doped nickel sample. The subsequently segregated graphene was characterized with low-energy electron diffraction (LEED), Auger electron spectroscopy (AES), helium ion microscopy and scanning tunneling microscopy (STM), among others. It was found at the atomistic level that the leading edge of graphene grows in stair-stepping fashion and the reconstructed c(2x2) impurity sulfur on the surface of Ni(110) experiences stress during the growth of graphene, as indicated by circuitry patterns seen with STM. The density of the sulfur stress patterns changes with the size and density of the graphene flakes, further confirming a direct relationship between the sulfur stress patterns and the growth of graphene.

$BiO(ClBr)_{((1-x)/2)}I_x$ Solid Solutions with Controllable Band Gap Engineering as Efficient Visible-Light Photocatalysts for Wastewater Treatment

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The goal of this project was to find an efficient photocatalytic material for wastewater treatment. The motivation is the high cost of water treatment by oil refineries, industrial plants, and domestic waste. According to the American Society of Civil Engineers, wastewater infrastructure alone will cost around $93 billion annually per state and around $285 billion to build infrastructure for the next 20 years. As a result, $BiO(ClBr)_{((1-x)/2)}I_x$ solid solutions were investigated because they are promising photocatalysts due to their efficient degradation capability, controllable band gap engineering, and activity in the visible light absorption spectra. The $BiO(ClBr)_{((1-x)/2)}I_x$ solid solutions were tested on water pollution simulants in the form of three types of dye — Methylene Blue, Rhodamine B, and Orange II — for proof-of-concept.

Effects of Doping on Boride Thermoelectrics

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Thermoelectric devices can recover energy lost from common processes such as waste heat. Borides, due to their stability at high temperatures as well as improvement of their thermoelectric properties as temperature increases make for good candidates for high temperature thermoelectrics. The Mori group has developed some n-type boride thermoelectrics, including yttrium aluminum boride, which are necessary because higher borides are predominantly p-type. This summer, yttrium aluminum boride compounds were synthesized and further doped with vanadium and manganese. Pellets were made by combining successfully-synthesized yttrium aluminum boride and either vanadium diboride or elemental manganese and heating in a spark plasma sintering system. Doping with transition metals lowered the Seebeck coefficient, but also lowered the resistivity of the material, resulting in as high as a 36% increase in power factor. Further annealing was carried out under both vacuum and argon. Annealing under vacuum improved the Seebeck coefficient while slightly lowering the resistivity, while annealing under argon significantly improved the resistivity but exhibited a decrease in Seebeck coefficient. The vacuum annealed sample's power factor increased an additional 73% over the un-annealed sample. Further work to be done includes investigating the effects of annealing on structure and doping materials with different transition metals.

Controlling Biofilm Formation through the Use of Conductive Polymers

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Biofouling is a phenomenon that occurs when bacteria create complex communities on surfaces, referred to as biofilm. These microbial systems consist of a variety of organisms that thrive within a self-assembled matrix, often very resilient to the external environment. This can prove to be a serious nuisance, as biofilm accumulation commonly occurs on marine vehicles, industrial pipelines, and biomedical implants, and can be very difficult to prevent and remove. Historically, biofilm growth has been combatted through the use of anti-fouling agents, which are a pollution risk to the outside environment. This work aimed to investigate biofilm production on the conductive, biocompatible polymer poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) under different oxidative states. A microtiter plate was patterned using photolithographic techniques, consisting of gold conductive lines and PEDOT:PSS pixels, and then assembled into a 96-well plate using commercially available silicon components. A continuous ±1 V bias was applied to adjacent gold lines, which were connected via minimal media, known to facilitate biofilm growth, to produce different oxidative states. Prior to biasing, an *Escherichia coli* (*E. coli*) biofilm was produced *in situ* to adhere to the polymer over variable time conditions, ranging from 0 to 22 hours. Preliminary results demonstrate that biofilms showed more adhesion to an oxidized surface after 22 hours of constantly applied bias, with greater surface area coverage on the oxidized polymer in comparison with the reduced. We postulate that reduced adhesion could be due to changes in hydrophobicity, as contact angle measurements show that oxidized PEDOT:PSS is more hydrophilic than the reduced alternative.