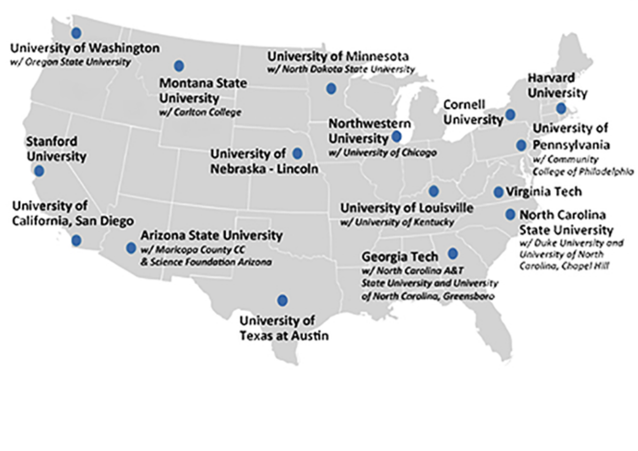
CNF
Cornell NanoScale
Science and Technology Facility

2019 NNCI REU Convocation

Hosted by Cornell NanoScale Facility (CNF)

Saturday - Tuesday, August 10-13, 2019

National
Nanotechnology
Coordinated
Infrastructure



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2019 NNCI REU Convocation Schedule

SATURDAY AUGUST 10

6:00-8:30 p.m., Pizza Party, Registration, & Get to Know You, Italian Carry Out Delivery, Baum Atrium

WE HAVE ADDED a SWING DANCE LESSON & DANCE to the EVENING!

SUNDAY AUGUST 11

8:00-9:00 a.m., Breakfast by Kendra's Culinary Creations, Baum Atrium, Duffield Hall

(We also have use of the Phillips Hall Lounge & Conference Room with continuous refreshments available there)

9:00-9:15 a.m., Welcome and Announcements, 101 Phillips Hall (main room)

9:15-9:45 a.m., Directors' Welcome; CNF Director Christopher Ober & NNCI Director Oliver Brand

9:45-10:05 a.m., break

Session A, 219 Phillips Hall *(Session Chair, Kathryn Hollar)*

Session B, 203 Phillips Hall *(Session Chair, Nancy Healy)*

10:53-11:15 a.m., break

Session C, 219 Phillips Hall *(Session Chair, Quinn Spadola)*

Session D, 203 Phillips Hall *(Session Chair, Joshua Heinemann)*

12:03-1:30 p.m., Lunch in Baum Atrium, Duffield Hall, Catered by Serendipity

1:30-2:30 p.m., 2019 iREU Interns Presentation with Dr. Lynn Rathbun, 101 PH

2:30-2:50 p.m., break

4:22-4:34 p.m., H32; Hammad Khan, Program Site: Montana State University

Agarose microchannels to study curvature effects in neuronal calcium signaling 24

4:34-4:46 p.m., H33; Joshua Ehizibolo, Program Site: Georgia Institute of Technology

Analysis of Thermal Management of Electric Motor 17

4:46-4:58 p.m., H34; Yumeki Tani, Program Site: Georgia Institute of Technology

Exosome Loading of Molecules using Microfluidic Devices 35

4:58-5:00 p.m., Announcements & Reminders, VIA EMAIL

5:00-6:00 p.m., Break to prepare for dinner trip

6:00 p.m., Buses at Schwartz Performing Arts Center to Dinner

6:30-8:30 p.m., Dinner at the Sciencenter!

MONDAY AUGUST 12

8:00-9:00 a.m., Breakfast by Cornell Catering, Phillips Hall Lounge & Conference Room

(We have use of the PHL&CR all day with continuous refreshments available there)

9:00-9:10 a.m., Welcome & Announcements, 101 PH

9:10-9:55 a.m., Fellowships Presentation with Dr. Lynn Rathbun, 101 PH

9:55-10:15 a.m., break

Session J, 219 Phillips Hall *(Session Chair, Ana Sanchez Galiano)*

10:15-10:27 a.m., J35; Briah Bailey, Program Site: Georgia Institute of Technology

Synthesizing Solid-State Electrolytes in Lithium-Ion Batteries. 12

10:27-10:39 a.m., J36; Brooke Hall, Program Site: University of Louisville

Semi-Automating the Process of Microassembly with a focus on Solarpede. 21

10:39-10:51 a.m., J37; Zane Ronau, Program Site: University of Louisville

Process Characterization of the Microscale Deposition Tools 31

10:51-11:03 a.m., J38; Scott Burlison, Program Site: The University of Texas at Austin

Controlled Thermal Oxidation of TMDs: TMO/TMD Interface 14

Session K, 203 Phillips Hall *(Session Chair, Julie Nucci)*

10:15-10:27 a.m., K39; Caroline Fedele, Program Site: Cornell University

Characterization of Superconducting Ruthenate Thin Films. 18

10:27-10:39 a.m., K40; Jarek Viera, Program Site: Cornell University

Growing 2D Transition Metal Dichalcogenides 37

10:39-10:51 a.m., K41; Jonathan Ortiz, Program Site: Cornell University

Improving the Reliability and Capability of PARADIM's MBE. 29

10:51-11:03 a.m., K42; Priscila Santiesteban, Program Site: Cornell University

Examining the Link Between Mechanical and Thermal Properties in Crystals 32

11:03-11:25 a.m., break

Session L, 219 Phillips Hall *(Session Chair, Amy Morgan Rose)*

11:25-11:37 a.m., L43; Ryan Mbagna Nanko, Program Site: Northwestern University

Structural Characterization of 2D Layered Complex Hetero-Ion Systems. 25

11:37-11:49 a.m., L44; Jakub Pepas, Program Site: Georgia Institute of Technology

Synthesis of CuZn Alloy Films through Electrodeposition 30

11:49-12:01 a.m., L45; Denise Hernandez, Program Site: Northwestern University

Synthesis of SnO_2/SiO_2 composites as High Capacity Anode Materials for Lithium ion Batteries 22

12:01-12:13 p.m., L46; Emily Katie Chase, Program Site: Georgia Institute of Technology

Synthesis of Pd-based Bimetallic twinned nanocubes. 15

Session M, 203 Phillips Hall *(Session Chair, Julie Nucci)*

11:25-11:37 a.m., M47; Samuel Straney, Program Site: Cornell University

Growth and Characterization of 2D Transition Metal Dichalcogenides 35

11:37-11:49 a.m., M48; Mr. Oluchi Onwuvuche, Program Site: Cornell University

Random Access Memory using Perovskite Materials 29

11:49-12:01 a.m., M49; Julia Trowbridge, Program Site: Johns Hopkins University

Synthesis and Characterization of Functional Transport Materials 36

12:01-12:13 p.m., M50; Pheobe Appel, Program Site: Johns Hopkins University

Analytical Modeling of Forced and Natural Convection in Molten Zones 11

12:13-1:00 p.m., Box Lunches, pick up in Phillips Hall Lounge & Conference Room

1:00-1:30 p.m., PHOTO SHOOT *(Gather in Baum)*

Group Photo First, then these three large site groups *(Georgia Institute of Technology and Harvard University; Cornell University (ALL—CNF REU, CNF iREU, PARADIM [Cornell and JHU])*

1:30-2:30 p.m., Presentation, 101 PH; Prof. Paul McEuen, Goldwin Smith Professor of Physics, Cornell University; "The Rise and Fall of Hendrik Schon: A Case Study in Scientific Fraud"

2:30-2:50 p.m., break

Session N, 219 Phillips Hall *(Session Chair, Alan Bleier)*

2:50-3:02 p.m., N51; Caroline Howell, Program Site: Georgia Institute of Technology

Strain Localization During Slow Strain Rate Testing of Sensitized Al-Mg Alloys 23

3:02-3:14 p.m., N52; David Murray, Program Site: Harvard University

Characterization of in situ TEM heating holders using silver nanocubes 27

3:14-3:26 p.m., N53; James Tran, Program Site: Cornell University

Area-Selective Deposition to Enable Single-digit nm Fabrication *36*

3:26-3:38 p.m., N54; Darien Nguyen, Program Site: Cornell University

Developing Microfluidic Devices for Assisted Reproductive Technologies *27*

Session P, 203 Phillips Hall *(Session Chair, James Overhiser)*

2:50-3:02 p.m., P55; Michael Straker, Program Site: Johns Hopkins University

Floating Zone Crystal Growth and Characterization of Boron Carbide *34*

3:02-3:14 p.m., P56; Anna Alvarez, Program Site: Cornell University

Light and Thermal Responsive Liquid Crystal Films for Micro Robotic Applications *11*

3:14-3:26 p.m., P57; Tai Nguyen, Program Site: Harvard University

Determining Origins of Water Contamination in ALD Oxide Films Using Deuterated Water *28*

3:26-3:38 p.m., P58; Colin Snyder, Program Site: Georgia Institute of Technology

Rapid Photo-Catalytic Oxidation of Dissolved Manganese with TiO_2 . . . . *33*

3:38-4:00 p.m., break

Session Q, 219 Phillips Hall *(Session Chair, Christopher Alpha)*

4:00-4:12 p.m., Q59; Jacob Baker, Program Site: Cornell University

Investigating the Effect of Environment Shape on Bacteria Growth at the Microscale *12*

4:12-4:24 p.m., Q60; Frank Yang, Program Site: The University of Texas at Austin

Fabrication and Characterization of IR Pixels for High Speed Detector Applications *38*

4:24-4:36 p.m., Q61; Gari Eberly, Program Site: University of Pennsylvania

Transparent MXene MicroECoG Electrodes for Multi-Modal Seizure Monitoring *17*

4:36-4:48 p.m., Q62; Patrice Constantin, Program Site: Harvard University

Characterization of Oxide Etch in Fabrication of InGaN QD Microdisks *16*

Session R, 203 Phillips Hall *(Session Chair, Leslie O'Neill)*

4:00-4:12 p.m., R63; Joe Stage, Program Site: University of Pennsylvania

Development of Thermally Actuated Tunable Adhesive Structures *34*

4:12-4:24 p.m., R64; Jordan Anspach, Program Site: Montana State University

Microspheres as Patterned Photoresist Bonding Spacers *11*

4:24-4:36 p.m., R65; Katie Munechika, Program Site: Cornell University

Microfluidic Chip Manufacturing for Point of Care Sepsis Diagnosis *27*

4:48-5:00 p.m., Announcements & Reminders, VIA EMAIL

5:00-6:00 p.m., Break to prepare for dinner trip

6:00 p.m., Buses at Schwartz Performing Center to Dinner

6:30-8:30 p.m., Dinner at the South Pavilion, Treman State Park

TUESDAY AUGUST 13

8:00-9:00 a.m., Breakfast by Cornell Catering, Phillips Hall Lounge & Conference Room

(We have use of the PHL&CR until lunch time with continuous refreshments available there)

9:00-9:15 a.m., Welcome & Announcements, 101 PH

9:15-10:15 a.m., Keynote Presentation, 101 PH;

Rudy J Wojtecki, IBM -- Almaden Research Center
"Quantum Computing and Chemical Modeling"

10:15-10:30 a.m., break

10:30-11:30 a.m., Career Panel, 101 PH

Panelists-

Kwame Amponsah, Founder and CEO, Xallent LLC; <kwame.amponsah@xallent.com>

Jaime Cardenas, The Institute of Optics, University of Rochester; <jcarden4@ur.rochester.edu>

Amrita Banerjee, CNF Research Associate, Electron-Beam Lithography; <banerjee@cnf.cornell.edu>

Mariela Rivera-De Jesus, Cornell Graduate Student in Biomedical Engineering; <mar524@cornell.edu>
ALSO! 2017 Keeping the Ezra Promise (KEP) REU Intern

Rudy J. Wojtecki, IBM -- Almaden Research Center; <rjwojtec@us.ibm.com>

11:30-12:30 p.m., Lunch in Baum, Catered by Corner Store Catering

12:40-1:00 p.m., Lisa Friedersdorf, Director of the National Nanotechnology Coordination Office (NNO), National Nanotechnology Initiative (NNI); via ZOOM in 101 Phillips Hall

1:00-1:30 p.m., poster set up

1:30-3:30 p.m., Poster Session in Duffield Hall Atrium

3:30-3:45 p.m., Clean up, final announcements, release

PRESENTERS

Professor Christopher Ober became the Lester B. Knight Director of CNF in July 2016. Prof. Ober states, "As the new CNF Director, I am excited about the new job and about the new opportunities afforded by the creation of the NNCI, a network focused on nanoscience and nanotechnology. As the users of CNF know, we have first-rate facilities and outstanding staff who are dedicated to helping our users achieve success in all their efforts. As a long time user of CNF myself, I am always very impressed with the enthusiasm of the staff for teaching new users and working with them to solve interesting and often difficult problems. We welcome inquiries from all researchers about CNF's capabilities and the new network."

Christopher Kemper Ober is the Francis Bard Professor of Materials Engineering at Cornell University. After several years in industry at the Xerox Research Centre of Canada, Ober arrived to Cornell as an Assistant Professor in 1986. His research is focused on lithography, patterning, the biology materials interface and control of surface structure in thin films. As a reflection of his contributions to lithography, Ober in 2015 was honored with the Photopolymer Science & Technology Outstanding Contribution Award. He is the 2006 winner of the American Chemical Society Award in Applied Polymer Science, and received a Humboldt Research Prize in 2007. In 2009, Ober was named a Fellow of the American Chemical Society and was awarded the Gutenberg Research Prize by the University of Mainz. Ober served as Interim Dean of Engineering 2009 - 2010. In 2014 he was a JSPS Fellow in Japan. More recently he was elected a fellow of APS (2014) and AAAS (2015).

Oliver Brand received his diploma degree in Physics from Technical University Karlsruhe, Germany in 1990, and his Ph.D. degree (Doctor of Natural Sciences) from ETH Zurich, Switzerland in 1994.

From 1995 to 1997, he worked as a postdoctoral fellow at Georgia Tech. From 1997 to 2002, he was a lecturer at ETH Zurich in Zurich, Switzerland and deputy director of the Physical Electronics Laboratory (PEL). In January 2003, Dr. Brand joined the Electrical & Computer Engineering faculty at Georgia Institute of Technology.

Dr. Brand has co-authored more than 120 publications in scientific journals and conference proceedings. His research interests are in the areas of CMOS-based microsystems, microsensors, MEMS fabrication technologies, and microsystem packaging.

Research interests:

- MEMS/NEMS
- Microsensors for Physical, Chemical and Biological Applications
- Microsensor Fabrication based on IC Technologies
- Microsystem Packaging

Dr. Lynn Rathbun received his B.S. in Physics from The Ohio State University in 1971. He attended graduate school at the University of Illinois where he obtained his M.S. (1973) and Ph.D. (1979) degrees in Physics, working with Prof. Gert Ehrlich on surface chemistry.

He joined the "submicron facility" at Cornell University in 1979 (yes, 40 years ago !) where he has been ever since. From 2004-2015 as Program Manager/Assistant Director of the National Nanotechnology Infrastructure Network (NNIN). He is currently the Laboratory Manager for the Cornell Nanoscale Facility (since 1994) and Associate Director for the User Facility of PARADIM, a materials by design center, since 2016.

He has been active in developing a variety of education and outreach programs for CNF, NNIN, and NNCI for more than 30 years. The "radical" idea of a network REU convocation where we fly students around the country to conference of their peers was in fact his, about 25 years ago!! Likewise, the idea of an international REU program for NNIN was a joint effort by him and Dr. Nancy Healy. He is proud to have shepherded these ideas into successful programs.

The Rise and Fall of Hendrik Schön: A Case Study in Scientific Fraud
Presented by Prof. Paul McEuen, Cornell University

In 2001, Hendrik Schön was the brightest star in condensed matter physics. The young researcher from Bell Labs was on an unprecedented streak, publishing groundbreaking papers on everything from lasers to molecular electronics at a rate of one paper every eight days. He had awards, job offers from major universities, and was on the fast track to a Nobel Prize. A year later, it all came crashing down. In this talk, we'll look at the rise and fall of Schön — how it happened, what went wrong, and what we can do to keep scientific fraud in check in the future.

Short bio: Professor Paul L. McEuen is the Goldwin Smith Professor of Physics at Cornell University. His scientific work focuses on the nanoscale, from nanotube transistors ten thousand times thinner than a human hair to ultra-strong graphene membranes only a single atom thick. He received his B.S. degree in Engineering Physics from the University of Oklahoma in 1985 and his Ph.D. in Applied Physics from Yale University in 1991. He joined the faculty at UC-Berkeley in 1992 before coming to Cornell in 2001. Awards and honors include a Packard Foundation Fellowship, a National Young Investigator Fellowship, and the Agilent Europhysics Prize. He is also a writer, and his debut novel **SPIRAL**, a scientific thriller, was published by Random House in March 2011.

Keynote Presentation: Quantum Computing and Chemical Modeling

Rudy J Wojtecki, IBM -- Almaden Research Center

The physical realization of multiqubit quantum computers (QCs) are extremely challenging as it requires the ability to control, manipulate and accurately measure an element exhibiting a quantum behavior. Recent work has demonstrated this with superconducting transmon qubits that behave like artificial atoms, acting as the quantum element capable of displaying properties of like superposition and entanglement but are macroscopic in size and composed of elements that can be handled in existing semi-conductor fabrication methods. While efforts to improving the quality of these devices have yielded progress to providing more powerful quantum computers capable of addressing more and more complex problems. While these QCs are a nascent technology, even on a system composed of 6 qubits IBM reported the development of software and uses the unique QC hardware that enabled the accurate modeling quantum systems H_2, LiH and BeH_2. Furthermore, the use of QC in a variety of simulations have been demonstrated that have implications in machine learning as well as artificial intelligence. As QC systems scale, the ability to simulate increasingly complex, and more useful, quantum systems will be realized. This talk will provide an introduction to QC hardware and the ability to exploit these systems in modeling complex systems.

Dr. Wojtecki graduated from Case Western Reserve University in 2013 with a Ph.D. in Macromolecular Science & Engineering under the auspices of Stuart J. Rowan (now at the Univ. of Chicago) and the support of a NASA GSRP fellowship. His graduate research focused on the synthesis of mechanically interlocked polymers composed -catenanes, chemical units that were the subject of the 2016 Nobel prize in chemistry on molecular machines (catenanes & rotaxanes). This work was recently published into the journal Science in a report titled "Poly[n] catenanes: The Synthesis of Molecular Chains."

In 2013 he joined IBM-Almaden Research Center after completion of his graduate work, as an engineer, and promoted to Research Staff Member in 2015. He is author of 24 peer reviewed scientific publications including a Nature Materials Review article with more than 800 citations. In 2017 he was recognized as an IBM Master Inventor after three and a half years at IBM for work highlighted in over 120 patent and patent applications. Dr. Wojtecki's current research efforts are geared to address the fabrication of superconducting qubits for quantum computers and is actively engaged in technical discussions, presentations & outreach on these technologies. For instance, recently, he served on a committee for a National Academies of Science Workshop on Quantum Technologies. In addition, working closely with IBM Semiconductor Research, he is developing materials for ongoing challenges in scaling that include area selective deposition for self-aligned processes and high-resolution lithographic materials.

Lisa Friedersdorf, PhD, Director of the National Nanotechnology Coordination Office (NNO), National Nanotechnology Initiative (NNI); via ZOOM in 101 Phillips Hall

Dr. Lisa Friedersdorf is the Director of the National Nanotechnology Coordination Office. She has been involved in nanotechnology for over twenty-five years, with a particular interest in advancing technology commercialization through university-industry-government collaboration. She is a strong advocate for science, technology, engineering, and mathematics (STEM) education, and has over two decades of experience teaching at both the university and high school levels.

While at the NNCO, Lisa has focused on building community and enhancing communication in a variety of ways. With respect to coordinating research and development, her efforts have focused on the Nanotechnology Signature Initiatives in areas including nanoelectronics, nanomanufacturing, informatics, sensors, and water. A variety of mechanisms have been used to strengthen collaboration and communication among agency members, academic researchers, industry representatives, and other private sector entities, as appropriate, to advance the research goals in these important areas. Lisa has also led the establishment of a suite of education and outreach activities reaching millions of students, teachers, and the broader public. She continues to expand the use of targeted networks to bring people together in specific areas of interest, including the Nano and Emerging Technologies Student Network and the U.S.-EU Communities of Research focused on the environmental, health, and safety aspects of nanotechnology. Nanotechnology entrepreneurship and nanomedicine are areas where new communities of interest are developing.

Prior to joining the NNCO, Lisa held a number of positions les at the intersection of academia, industry, and government. At Lehigh University, Lisa served as the associate director of the Materials Research Center and director of the industry liaison program. In this role, she oversaw dozens of membership programs and was responsible for developing and coordinating multi-investigator interdisciplinary research programs including a multimillion-dollar public-private partnership in microelectronics. As director of the Virginia Nanotechnology Initiative, she led an alliance of academic institutions, industry, and government laboratories with an interest in nanotechnology across the Commonwealth of Virginia. At the University of Virginia, she served as managing director of the nanoSTAR Institute and led the development of pan-university initiatives as a program manager in the Office of the Vice President for Research. Additionally, Lisa has been active in the start-up ecosystem for many years assisting small companies with business development and access to resources, and vetting emerging technologies for investors.

Lisa earned her PhD and MSE in Materials Science and Engineering from the Johns Hopkins University and BS in Mechanical Engineering from the University of Central Florida.

NNCI REU ABSTRACTS by LAST NAME

Light and Thermal Responsive Liquid Crystal Films for Micro Robotic Applications

Anna Alvarez, Mechanical Engineering, University of Illinois at Urbana Champaign

NNCI REU Principal Investigator: Itai Cohen, Physics Department, Cornell University
NNCI REU Mentor: Qingkun Liu, Cornell University
Contact: annava2@illinois.edu, itai.cohen@cornell.edu, ql59@cornell.edu

Multifunctional micro-sized soft robotics are poised to revolutionize drug delivery, surgical operation and many other biomedical applications. However, building such microrobots with a variety of functionalities is challenging due to the lack of fabrication technologies for responsive materials at the microscale. In this research, I developed a scalable microfabrication technology to build light- and thermal-activated microrobots using liquid crystal (LC) polymers, known for their facile response to even relatively weak applied stimuli. First, ultraviolet light curable precursor containing LC oligomers has been developed, allowing for patterning the LC microrobots using photolithography. Second, trichlorofluorosilane-coated silicon microgrooves were used to define the unidirectional alignment direction of LC films. Finally, the LC films will contract along the alignment direction when experiencing a phase transition from the LC phase to its isotropic phase induced either by heat or light. These LC films could further bend as hinges if another athermal photoresist is patterned atop of the LC films, allowing 2D patterned films to fold into 3D objects. Fabricating these LC-based responsive microrobots in a scalable way will provide a powerful platform for dynamically reconfigurable micro-sized origami-robots.

Microspheres as Patterned Photoresist Bonding Spacers

Jordan Anspach, Electrical Engineering, Montana State University

NNCI REU Principal Investigator: David Dickensheets, Electrical Engineering, Montana State University
NNCI REU Mentor: David Dickensheets, Electrical Engineering, Montana State University
Contact: jordananspach@gmail.com, davidd@montana.edu

During the fabrication process of many microelectromechanical systems (MEMS) bonding of two patterned wafers is required. Often, the flatness and overall quality of this bond is important to the final design. In the case of the deformable mirrors being created in this project, the flatness and uniformity of the bond is crucial to the usability of the finished product. This investigation introduces the idea of using microspheres mixed into the chosen photoresist as non-deformable bond line spacers. Both the negative epoxy-based photoresist SU-8, and positive PR1-4000A1 photoresist were used in these experiments. Additionally, both soda-lime glass and silica microspheres with varying mixing methods, bond temperatures and forces, and photoresist patterning parameters were attempted. This presentation will cover the process of, and main problems faced when implementing this method, as well as the final bonding results after optimization.

Analytical Modeling of Forced and Natural Convection in Molten Zones

Pheobe Appel, Chemical Engineering, Purdue University

PARADIM REU Principal Investigator: Prof. Tyrel M. McQueen, Chemistry, Physics and Astronomy, and Materials Science and Engineering, Johns Hopkins University
PARADIM REU Mentor: Dr. W. Adam Phelan, Chemistry, Johns Hopkins University
Contact: appelp@purdue.edu, paradim@jhu.edu

A floating zone crystal growth procedure is utilized to grow large, bulk single crystals of interesting materials to further investigate properties such as electronic, magnetic or strength. This procedure is a direct melt process used to grow single crystals with two rods connected by a molten center. The molten zone is maintained when the feed, or top, rod is constantly melting and the seed, or bottom, rod is constantly solidifying via downward translation.

The molten zone is a non-isothermal liquid bridge which causes natural convection and since the rods are moving by translation and rotation, there is forced convection component as well. The stability of the liquid bridge can be controlled based the speed of the rods and adjustments of heat. To more easily predict which settings will work best and provide the most stable molten zone for a given material, a dimensionless analytical model was developed, factoring in unexplored components such as, gravity, motion of the rods, wind driven shear force on the free surfaces of the melt, the complex geometry of the molten zone and, the effect of phase change temperature gradient. The proposed model accounts for the aforementioned assumptions which provides a more complete view of the fluid flow within the molten zone.

Synthesizing Solid-State Electrolytes in Lithium-Ion Batteries

Briah Bailey, Biochemistry, Claflin University

NNCI REU Principal Investigator: Dr. Nian Liu, Materials Science, Georgia Institute of Technology
NNCI REU Mentor: Tianqi Hao, Chemical and Biomolecular Engineering, Georgia Institute of Technology
Contact: briahbailey1@gmail.com, nian.liu@chbe.gatech.edu, thao34@gatech.edu

Lithium-ion based batteries traditionally use a liquid electrolytic solution as a mean to move Lithium ions back and forth during charge and discharge. Liquid electrolytes have proven to be extremely flammable which risks safety concerns if the battery overheats. There's also the problem of dendrite production by metal deposition in the battery where they could grow during recharging of the battery and reach the cathode, causing premature short circuiting. These problems led to the development of solid-state electrolytes that will rid of the flammability risk that accompanies liquid electrolytes while also only allowing Lithium-ions to exit at certain locations, decreasing the risk of dendrite production. The focus of this project is to synthesize a solid-state electrolyte where Lithium Tin Phosphorous Sulfide (LSPS), a superionic material, is effectively utilized due to its high ionic conductivity. This was accomplished by combining LSPS via the solvent, Toluene, with Polystyrene-Block-Poly (Ethylene-Ran-Butylene)-Block-Polystyrene (PBP) in order to combat its moisture sensitivity and Polyethylene Glycol (PEG) to aid in retaining LSPS's initial ionic conductivity. A solid pellet of LSPS, PBP, and Toluene was created first where there was a lack of oxidation, PBP effective, but the Electrochemical Impedance Spectroscopy (EIS) curve that accompanied this sample proved it to have an undesirable ionic conductivity. This development led to the inclusion of PEG to the overall sample which produced an ionic conductivity of 1.11 x 10^{-3} S/cm which is a desired conductivity when comparing it to liquid electrolytes and pure LSPS.

References; 1. Zhang, J., et al. (2016). Flexible and ion-conducting membrane electrolytes for solid-state lithium batteries: Dispersion of garnet nanoparticles in insulating polyethylene oxide. Elsevier,28, 447-454. 2. Zheng, B., et al. (2018). Stabilizing Li10SnP2S12/Li Interface via an in Situ Formed Solid Electrolyte Interphase Layer. ACS Applied Materials & Interfaces,10(30), 25473-25482. doi:10.1021/acsami.8b08860

Investigating the Effect of Environment Shape on Bacteria Growth at the Microscale

Jacob Baker, Biomedical Engineering, University of Arizona

NNCI REU Principal Investigator: Guillaume Lambert, Applied and Engineering Physics, Cornell University
NNCI REU Mentor: Matthew Henriques, Applied Physics, Cornell University
Contact: jacobbaker@email.ariona.edu, lambert@cornell.edu, mdh324@cornell.edu

E. coli bacteria are sensitive to pressures exerted by their physical environment. The constraints that differently shaped growth chambers have on cell populations over time are a significant extension of this fact and play a part in characterizing bacteria growth. By utilizing the resources of the Cornell NanoScale Facility, we create a microfluidic device that features a large central fluid distribution chamber and hundreds of tiny growth chambers designed to grow bacteria at a 1 µm height display to view different test geometries and analyze their growth patterns. The device is produced by spinning micrometer thick layers of negative photoresist onto a silicon wafer and exposing to create a pattern designed in L-Edit CAD software. The wafer serves as the mold for the actual device, which we cast in PDMS. This creates reproducible devices with channels for bacteria and nutrients to flow through and grow. A type of *E. coli* is genetically engineered to produce fluorescent bacteria that don't produce biofilms and are grown separately before being injected into the device. The results of this experiment play a part in widening the pool of knowledge for under what conditions bacteria thrive or stagnate, crucial data towards solving World Health Organization global health challenges such as antimicrobial resistance.

Characterizing Skeletal Microstructure with High-Resolution Nondestructive 3D X-ray Microscopy

Kate Baldridge, Quantiative Biology, University of North Carolina at Chapel Hill

NNCI REU Principal Investigator: Dr. Jacob Jones, Material Science and Engineering, North Carolina State University
NNCI REU Mentor: Dr. Jaqcueline Cole, Biomedical Engineering, North Carolina State University
NNCI REU Mentor: Emily Fawcett, Biomedical Engineering, North Carolina State University
Contact: kbaldri@ncsu.edu, JacobJones@ncsu.edu

High-resolution imaging is essential for musculoskeletal research, in particular visualizing features and analyzing structural integrity in different tissues and at multiple length scales. Micro-computed tomography (micro-CT) facilitates nondestructive 3D analysis of microstructure, but conventional systems lack sufficient resolution to characterize submicron-scale features contributing to macro-scale function. Recent technological advances introduced 3D X-ray microscopy (XRM), with unique two-stage magnification in which the image is geometrically then optically magnified. XRM systems enable 3D imaging of large samples at submicron resolution, bridging the gap between microscopy techniques and micro-CT. Our objective was to use XRM (ZEISS Xradia 510 Versa) to examine microstructural features in cortical bone (e.g., porosity) unaccessible by micro-CT. We used rat humeri from a study on brachial plexus birth injury (BPBI), the most common nerve injury in children, causing muscle paralysis, shoulder deformities, and long-term arm impairments. Nerve injury location relative to the dorsal root ganglion (postganglionic or preganglionic) affects injury progression. Using a rat BPBI model, different microstructural deficits in underlying trabecular bone have been seen using micro-CT, but the effects on cortical bone microstructure are unknown. We scanned humeri from three test groups with XRM. Images were reconstructed and segmented to isolate cortical bone, and volumes of interest were selected. Cortical microstructure was analyzed and compared between pre- and postganglionic injury. With XRM we saw a decrease in mean pore diameter, and an increase in pore density after preganglionic injury. Determining differential microstructural changes with injury location will expand understanding for injury consequences and may inform treatment strategies.

Humidity Controlled Tuning of Hybrid Distributed Bragg Reflectors (DBR)

Elizabeth Bellott, Mechanical Engineering, North Carolina State University

NNCI REU Principal Investigators: Dr. Shannon Yee, Woodruff School of Mechanical Engineering, Georgia Institute of Technology; Dr. Natalie Stingelin, School of Chemical & Biomolecular Engineering/ School of Materials Science & Engineering, Georgia Institute of Technology
NNCI REU Mentors: Daron Spence, School of Materials Science & Engineering, Georgia Institute of Technology; Alex Balzer, School of Chemical & Biomolecular Engineering, Georgia Institute of Technology
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To reduce energy consumption in buildings, reflective coatings with Distributed Bragg Reflector (DBRs) structures were proposed for rejecting thermalizing near-infrared radiation. Additionally, these coatings were exposed to controlled levels of humidity to determine the degree of switchability that can be obtained through shifting and reducing the resulting photonic stopband between the visible and infrared spectrums. Cheap, readily accessible materials, such as titanium hydrate/PVAl hybrid and poly(methyl methacrylate)(PMMA), and the fabrication process of dip coating were considered for scalability and simplicity of future production. Control over the movement and adjustment of the stopband within the DBR structure itself was explored through profilometry measurements, the addition of bilayers, annealing, and alternative DBR structures. Lastly, the DBR structure was coated upon additional substrates to determine possible reflectance of the infrared. A stopband in the infrared was confirmed with transmittance and reflectance data obtained via UV Visible Spectroscopy. The stopband was able to be moved and adjusted as well as expanded in wavelength range within the near-infared spectrum. Swell testing of the DBR structures revealed that humidity reduced reflectivity, allowing more transmittance of infrared light. Upon redrying, the stopband and its band width can be substantially restored to reflect the infrared, confirming switchability. Finally, results for the DBR structure coated upon poly(propylene) revealed that reflectance of the infrared from other substrates is possible.

Fabrication and Optimization of a Schottky Diode Utilizing Field Plate Termination

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Power semiconductor devices are discrete circuit components which can operate under high currents and voltage. They are mostly used for optimizing the efficiency of high-power conversion systems. Schottky diodes are a type of power device which are fabricated by making a contact between a metal and a semiconducting substrate. These devices exhibit fast switching characteristics from low charge buildup in the ON state but have from relatively high leakage currents and relatively low blocking voltage.

To reduce electric field crowding at the contact edge, the design of a simple, circular anode silicon Schottky device was modified to include a field plate and a silicon dioxide passivation layer. A simulation split determined the optimal field plate length and passivation thickness. Photolithography and etching were used three times to isolate the device, expose the contact after the passivation layer was applied, and to define the field plate. An ohmic titanium contact was deposited on the back of the substrate and annealed. Nickel was deposited to the top of the substrate and metal liftoff defined the Schottky contact and field plate. The field plate and passivation layer increased the breakdown voltage from 40 to 76.5 volts and showed low leakage current.

Growth and Characterization of Monolayer $MoSe_2$ using Chemical Vapor Deposition

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With silicon reaching its physical limit, transition metal dichalcogenides (TMDs) are emerging as a prospective replacement. $MoSe_2$, like other TMDs, faces laborious synthesis techniques, such as exfoliation, that cannot be scaled up to an industrial level. Chemical vapor deposition (CVD) can produce large areas of TMDs at a higher rate but with slightly compromised crystalline quality. This research aims to (a) optimize the growth of large, high-quality $MoSe_2$ monolayers using CVD and (b) observe the influence of various parameters on growth. A custom-made tube furnace was used to grow $MoSe_2$ on Si/SiO_2 substrates. A single parameter in the system was changed with each sample while keeping all other parameters consistent. The parameters examined in this research were growth temperature, growth time, and molybdenum flux. Optical microscopy, Raman spectroscopy, and photoluminescence spectroscopy were used to characterize each sample and examine the effects of changing parameters. The crystalline quality and size of $MoSe_2$ domains were used to determine the optimal growth conditions. Trends were identified that influenced the quality of the grown material and can later be used for further improvement. The optimized recipe can be used to consistently grow uniform $MoSe_2$ monolayers that are greater than 100 µm in length and of highly ordered crystalline quality.

Controlled Thermal Oxidation of TMDs: TMO/TMD Interface

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The electronic industry, particularly the microprocessor industry has been driven and flourished for over five decades due to increased performance, speed and robustness of products. Basic performance improvement was mainly due to the size shrink of transistors (basic building block of microprocessors) with regards to Moore's law. Recently, the industry has reached the fundamental lateral size for traditional silicon material governed by quantum mechanics. To continue scaling down and keeping up with the pace of industry, a new material system is very much needed. Atomically thin transition metal dichalcogenides (TMDs) offer sizable bandgap (~1-2 eV) and excellent gate controllability due to the thin nature of the materials. However, a native oxide like the Si/SiO_2 system is still missing. To improve logic transistors for microprocessors, a high-quality transition metal oxide (TMO) / TMD system is necessary. In this project we have optimized a recipe for developing a MoS_2/MoO_3 system (MoS_2 is a potential TMD for replacing silicon) with thermal oxidation. To achieve this, a modified mechanical exfoliation method was developed to obtain large-area monolayer and few-layer MoS_2 flakes. Raman, photoluminescence, and x-ray photoelectron spectroscopy were then used to verify the presence of a native TMO, as well as the pristine nature of the TMD under the TMO.

Effectiveness of Grown Poly(methyl methacrylate)/PMMA Brush as a Masking Agent

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In the field of nanoscale fabrication, there is an interest in developing entirely bottom-up fabrication methods for nanoscale devices, building them atom by atom. One bottom-up fabrication process in development is Selective CoAxial Lithography via Etching of Surfaces (SCALES) (Mohabir et. al., submitted) where a polymer brush is grown or polymerized from the surface of a nanostructure and subsequently etched from desired areas, creating a polymer mask which patterns the surface and enables area-selective atomic layer deposition (AS-ALD). The focus of this project is to analyze and investigate the effectiveness of grown poly(methyl methacrylate) (PMMA) as a masking agent for the AS-ALD process. This work will help in the continuing development of the SCALES process as well as demonstrate its viability for making functional electronic devices. Grown p.m.MA brushes were run through ALD processes along with bare silicon (control) and spin coated p.m.MA (industry baseline). The substrates were then analyzed with X-ray photoelectron spectroscopy (XPS) to determine chemical changes and compare the deposition amounts on each substrate. The p.m.MA brush thickness, ALD temperature, ALD purge time, and ALD precursors were varied to determine optimal ALD process conditions for the grown p.m.MA to act as a mask. It was found that the precursor played the most important role in determining the grown p.m.MA's masking abilities; the current hypothesis is: more sterically hindered precursors are less likely to diffuse through p.m.MA. Additionally, purge time was found to minimize precursor absorption into p.m.MA.

Synthesis of Pd-based Bimetallic twinned nanocubes

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The generally high cost of noble metals paired with an increase in demand necessitates the maximization of their efficiency in their target applications. This can be accomplished through controlled synthesis of noble metal nanocrystals with well-defined morphologies. For bimetallic nanocrystals, understanding the interactions between two metals is critical for achieving desired structures with optimized properties.

In this work, we use Pd nanoplates as seeds/substrates to investigate their interactions with different metals (copper, silver, and gold) under various reaction conditions. When a sufficient amount of metal precursor is added to the system, the final morphology of the nanocrystals is determined by the presence of defects on the Pd plate, the use of a capping agent, and the intrinsic metal properties such as lattice mismatch. By reducing the concentration of metal precursor added to the system to a varying degree, the growth behavior of the nanocrystals can be observed, revealing how the interaction between the Pd plates and each metal differs. Using UV-vis spectroscopy and TEM imaging, we were able to observe the layer by layer growth pattern of silver, and the island growth pattern of gold.

Utilizing Raman Spectroscopy to Study the Aqueous Recovery of Phosphate Pollutants

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The demand for phosphate sustainability has increased due to depleting phosphate rock deposits, vital for global food supply, and widespread phosphate pollution of surface waters, which leads to eutrophication, hypoxia, and dead zones. Several compounds have been tested for their phosphate recovery properties in aqueous solutions, including magnesium oxide, lanthanum chloride, and iron oxide. This research aims to evaluate the efficacy of Raman spectroscopy (RS) to study these recovery agents. These compounds were analyzed with the Horiba XploRA PLUS Raman microscope. The possible advantage to using RS over traditional vibrational techniques such as infrared spectroscopy is attributed to water's Raman inactivity across many regions of spectral interest.
The products of each phosphate recovery agent produced uniquely identifiable spectra meaning RS could be used to study these reactions further. Additionally, data suggest that RS can be used to quantify phosphate concentration in aqueous solutions at low concentrations, though not at lower, environmentally relevant concentrations. Laser wavelength, power, and acquisition time significantly affected the signal-to-noise ratio and intensity of spectra; therefore, developing the right methodology can extend the lower limit of detection. For future study, phosphate recovery reactions could be monitored via the RS peak intensity of phosphates *in situ*.

Characterization of Oxide Etch in Fabrication of InGaN QD Microdisks

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Low-Cost Solar Cell Technology for Heterogenously Integrated Systems

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Perovskite Solar Cells (PSCs) is an area of study that has grown exponentially in the past decade. Their sudden popularity is due to several factors; most notably that they are highly effective in increasing power conversion efficiency of solar cells, at low production costs. A perovskite material is a specific crystalline structure, of the general formula ABX3. A and B are cations, where A is greater in size than B, and X is an anion bonded to both cations. They are generally a hybrid organic-inorganic lead/tin halide, and are desirable for their flexibility, ease of management, low cost, and lightweight nature. This project focuses on researching the optimization of this material to achieve the greatest power conversion efficiency, while also keeping production costs low. Several different factors are considered when researching which material is ideal, such as challenges to be overcome; voltage current density hysteresis, and long-term stability/lifetime. Numerous perovskite materials and their material properties were reviewed, and methylammonium tin tri-chloride was chosen as the preliminary ideal perovskite layer material, due to its low production costs, chemical and thermal stability, and overall increased efficiency of PSCs. The final step in the project was to create and simulate the 2D device using TCAD Sentaurus Software. Once the material's properties were added, the mesh was built. The simulations run relay information about the electron and hole transport in the device. Due to time constrictions, the TCAD simulations were not run.

Transparent MXene MicroECoG Electrodes for Multi-Modal Seizure Monitoring

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Treatments for epilepsy may be advanced based on insights gained through simultaneous imaging and electrophysiological recording of seizures at the microscale; few microelectrode technologies are capable of these measurements. MXenes, a family of 2D carbon-based materials, have shown promise for realizing transparent, low impedance microelectrodes due to their high conductivities and low optical transparencies. To systematically evaluate the effect of MXene film thickness on electrode impedance and transparency, $Ti_3C_2T_x$ MXene electrodes were fabricated using microfabrication techniques with a range from 5 to 15 spray-coated MXene layers. Electrochemical impedance spectroscopy was acquired in 10 mM phosphate buffered saline to measure electrode impedance. Electrode transparency was acquired through UV-Vis spectroscopy. EIS analysis indicated a significant decrease in electrode impedance as the amount of MXene spray-coats increased; at 1kHz, the 5, 10, and 15 spray-coat $Ti_3C_2T_x$ electrodes presented impedances of 280 ± 203 kΩ , 46 ± 14 kΩ, and 5 ± 1 kΩ, respectively. Graphene electrodes exhibited an impedance of 2110 ± 98 kΩ. At 550 nm, a common wavelength of light employed in calcium fluorescence imaging, the average transmittance of light through the 5, 10 and 15 spray-coat $Ti_3C_2T_x$ films were 74 ± 1%, 68.2 ± .8% and 44.2 ± .5%, respectively. The electrochemical properties of $Ti_3C_2T_x$ described here indicate the phenomenal potential of MXene spray-coated films in the fabrication of microECoG devices and other biosensors.

Analysis of Thermal Management of Electric Motor

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Electric vehicles (EVs) are important in reaching a sustainable environment. Research shows that their capacity is limited due to temperature rise in the motor, one of the main components of an EV. Traditionally, the motor is cooled using a cooling jacket to reduce its outer temperature. This project aimed to develop a model of the motor to analyze its thermal characteristics and temperature rise, and explore options for better thermal management. In the thermal analysis of the BMW i3, the maximum temperature was found at the stator windings, with temperatures rising above 300K for power densities of 0.5×10^6 W/m^{3}K - 3×10^6 W/m^{3}K. To explore cooling the motor internally, a thin air gap was created around each winding of the stator.

The properties of the gap can be replaced by fluids of different thermal properties to further test impact of heat generation.

Reference: Zabdur Rehman & Kwanjae Seong, 2018."Three-D Numerical Thermal Analysis of Electric Motor with Cooling Jacket," Energies, MDPI, Open Access Journal, vol. 11(1), pages 1-15,

Regulation of Stem Cell Density and Functions by Micropatterned Surfaces

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Cell density plays a vital role in regulating cell functions, such as adhesion and spreading, proliferation, and differentiation. In this study, photo-reactive azidophenyl-derivatized poly(vinyl alcohol) (PhAzPVA) was synthesized by introducing azidophenyl groups into PVA. The micropatterns with different square densities were prepared by coating PhAzPVA on a PS plate using photolithography. Cell density could be controlled by the

micropatterns and the influence of cell density on cell functions was investigated. The results showed that the as-prepared microsquares were similar with that of the pre-designed photomask and the cell density could be well adjusted by these micropatterns. Organization of actin filaments and DNA synthesis activity were observed by immunefluorescence staining.

Prediction of B-cell Epitopes on Chikungunya and *T. cruzi* Proteomes

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Chikungunya and Chagas are two neglected and re-emerging infectious diseases that pose worldwide health problems to humans. Chikungunya is a virus that infects people by a mosquito vector, specifically the *Aedes genus*. According to the Centers for Disease Control, in 2014, cases in 46 U.S. states were identified. Chagas disease is caused by the parasite *Trypanosoma cruzi* and is transmitted to people by the triatomine vector. In the U.S., there are currently no vaccines for these two diseases. A limitation for the prevention of these two diseases is lack of known immunogenic B-cell epitopes. The objective of the project was to predict B-cell epitopes on the Chikungunya proteome. A second project was to utilize the ELISA assay to test predicted peptide sequences on the *T. cruzi* proteome. The hypothesis behind the projects: If a large dataset generated from a peptide microarray which represents amino acid sequence space can be used to train a machine learning method, then it can predict B-cell epitopes on the Chikungunya viral proteome to differentiate between Chikungunya infected human serum and Non-Chikungunya infected human serum. The results from the first project showed that a machine learning method can predict known and new Chikungunya epitopes. The results from the second project showed that the predicted epitopes can differentiate between *T. cruzi* infected serum and Non-*T. cruzi* infected serum. Further research is needed to test the new predicted Chikungunya epitopes and to reproduce the results from the predicted *T. cruzi* epitopes.

Characterization of Superconducting Ruthenate Thin Films

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Superconducting materials are useful for a variety of applications, mainly quantum devices and powerful electromagnets. Strontium ruthenate, Sr_2RuO_4, is a complex oxide, which forms in the Ruddlesden-Popper structure. This material superconducts below a critical temperature (T_c) of about 1.5 K, and although this is considered a low T_c superconductor, we are interested in it because of the potentially exotic odd-parity pairing symmetry of the electron Cooper pairs. The proposed odd angular momentum quantum number of Sr_2RuO_4 corresponds to a triplet spin state, where the electron pairs have a combined spin of one (three states), instead of zero (one state) as with even-parity superconductors. Previously, our group has successfully synthesized superconducting thin films of Sr_2RuO_4 on various substrates, in order to understand how the superconducting properties of this exotic superconductor can be manipulated by strain. However, in this presentation, I will discuss an equally exciting research route, where we aim to synthesize a new material that will potentially exhibit odd-parity superconductivity as well. The goal of our research this summer has been to synthesize the tetragonal polymorph of Ba_2RuO_4, which is isostructural and isoelectronic to Sr_2RuO_4. Using molecular beam epitaxy, we have successfully grown metallic Ba_2RuO_4 thin films, with record quality as demonstrated by a residual resistivity ratio ($\frac{\rho\,(300\,K)}{\rho\,(4\,K)}$) of 30 in our best film. After growth and initial characterization, we have further characterized the material using X-ray diffraction and electronic measurements, and these results thus far offer promise of a new spin-triplet superconductor.

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Zinc Oxide (ZnO) thin films have been used commercially and are gaining traction as a reliable transparent oxide semiconductor material. Recent research has suggested that ZnO thin films are unique semiconducting oxides in that the hydrogen defects counteract the prevailing conductivity. Because of this, it is important to understand the effects of hydrogen impurities within the crystal lattice. This includes the effects that different deposition conditions have on hydrogen impurity formation as well as the effects that the impurities have on the electrical characteristics of the thin films. This project aims to explore the nature of hydrogen impurities in ZnO thin films by introducing a controlled hydrogen treatment. Varied deposition conditions were studied and the resulting thin films were characterized physically and chemically. The deposition conditions tested in this project were temperature and substrate type; either glass, sapphire plane-A, or sapphire plane-C. Electrical characteristics were measured before and after a controlled hydrogen plasma treatment. The deposition was performed by magnetron sputtering. Electrical characterization was performed by Hall Effect measurement and 4-Point Probe. Elemental data and crystal lattice data were obtained by XPD and XRD, respectively.

Novel Ridge Geometries for Use in Microfluidic Devices for Cell Sorting

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The medical community has methods to sort cells by cell type, such as centrifugation and flow cytometry. However, certain areas of medical research, such as Celgene's collaboration with Dr. Sulchek would enable immunotherapy medications by providing a label-free, low manipulation method for viability sorting. The microfluidic devices developed by the Sulchek lab group sort the viable cells from the nonviable cells by exploiting the cells' compressibility. The cells are suspended in a buffer fluid and flowed through a primary channel over angled ridges. Hydrodynamic forces cause the compressible viable cells to slip under the ridges whereas the less compressible non-viable cells are deflected into a gutter leading to separate outlet sites. Conventional photolithography techniques have limited the ridges to a rectangular geometry, but the Photonic Professional GT instrument from Nanoscribe uses two photon lithography to allow a single workflow to fabricate novel ridge geometries including triangular, trapezoidal, circular, and concave to study the effect of ridge geometry on cell deflection. Using this instrument introduced problems not encountered when fabricating the molds using standard photolithographic techniques such as mass device production, possible mold degradation, lowered ridge resolution, the surface roughness of the mold, and total fabrication time. After addressing these problems, a full device with triangular ridges was fabricated, which showed deflection of nonviable cells not previously deflected by rectangular ridges. Research into the efficacy of these novel ridge geometries are ongoing, but we have successfully provided a proof of concept.

The Effect of Substrate Stiffness on Perineuronal Net Development *in vitro*

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Perineuronal Nets (PNNs), specialized structural components of the extracellular matrix (ECM) in the brain, surround neurons and play important roles including synaptic stabilization in the adult brain. Traumatic Brain Injury (TBI) alters the structure of the ECM, particularly through PNN degradation. This affects the excitation-inhibition balance in the brain and may set the conditions for vulnerability to secondary trauma, such as epileptogenesis. TBI has been modeled *in vitro* to study neuronal network behavior; however, there is currently limited literature on the effects of TBI on PNNs. Traditional PNN development *in vitro* in extremely stiff microenvironments is incomparable to the native stiffness of the brain. Currently, the effects of substrate stiffness on PNN development *in vitro* remain unknown. In order to study this relationship, we must first sufficiently culture specific neuronal ECM structures *in vitro*. We aim to promote the natural growth and development of PNNs *in vitro* by mimicking the brain's physiological stiffness *in vivo*. To model this, we microcontact print PLL onto PDMS (polydimethylsiloxane) substrates of varying stiffness in a grid-pattern to control neuronal network connectivity and density, therefore standardizing the growth environment. Controlled patterning will enable the quantification of neuronal growth and PNN development. We expect that the physiologically softer PDMS substrate will be more conducive to the development of PNNs *in vitro* due to its similarity to the *in vivo* brain microenvironment. Therefore, we hope to extend the current model of TBI *in vitro* to study how PNNs affect the sensitivity of neurons to mechanical trauma.

Fabrication of μ-scale Electrodes for Periodic Poling in Nonlinear Optical Crystals

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High-quality patterned electrodes having a suitable size and spacing are essential for periodic poling of nonlinear optical crystals. The focus of this project was to optimize the process recipe to produce features that consisted of micron-scale metal gratings connected to an electrical contact pad using photolithography and wet etching techniques. These features were fabricated on fused silica substrates that had undergone a chromium deposition with a nominal thickness of 75 nm. A number of test patterns with metal line widths of 2 μm and 4 μm and various spacing have been investigated. For this set of masks, we found fairly consistent reproducibility with a photolithography exposure of 33.2 mJ/cm^2 on the AB-M Contact Aligner and 108 seconds development time using AZ 300 MIF Developer. Based on our results, an approximate ±10% change in exposure or development time will not cause a noticeable change in the structure quality or feature sizes. Variations in fill factor of approximately 5% were noted in samples produced in a nominally identical way. The causes of this variation are under investigation.

Fabrication and Characterization of Contacts for Chalcopyrite-based Thermoelectric Module

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Approximately 66% of the energy consumed in applications such as automobiles, factories, incinerators, powers plants and other machinery is lost to waste heat, a majority of which is under 150°C [1]. The ability to efficiently harness this lost energy for other applications would revolutionize energy consumption in society, therefore efforts in the thermoelectric industry focus on the development of ZT-enhanced thermoelectric materials such as n-type chalcopyrite for low temperature ranges [2]. In a recent collaboration the Thermal Energy Harvesting Group observed efficiency losses in a fabricated thermoelectric module due to poor electrical contact at the junction between the electrode and the thermoelectric material. The goal of this study is to survey potential contacts metals for n-type chalcopyrite and develop a high throughput one-step spark plasma sintering fabrication method to ease device fabrication. Over the course of the project, six metals with varying affinities for chalcopyrite were explored and three different setups for the one-step fabrication were tested: powder/chalcopyrite powder, powder/foil/chalcopyrite powder, foil/chalcopyrite powder. It was observed that the amount diffusion of the metal into the thermoelectric material has a direct relationship to the bond adhesion and an inverted relationship to the maintenance of thermoelectric properties. Large diffusive regions hinder thermoelectric performance while minimal diffusion limits bond strength and thus the lifetime of the device. Future work will utilize the results to fabricate a low temperature thermoelectric module and characterize its efficiency.

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PC transfer optimization for van der Waals heterostructures

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The celebrated discovery of graphene in 2004, a 2D hexagonal crystal [1], opened a door for many condensed matter experiments which before were not accessible. Many research labs around the world started to explore different aspects and realize a variety of devices to understand the physics which governs the 2D atomic scale. Soon after graphene other 2D materials were predicted and realized, single or few layers atomic thick. Some of these well-known 2D materials are Boron Nitride and Transitional Metal Dichalcogenides (TMDCs). The crystals are bonded together by out of plane van der Waals interactions. By stacking these 2D sheets in a careful manner we can create new artificial material with the desired properties. This process includes stacking of different materials as well as manipulating the lattice orientation during stacking. These new heterostructures provide a promising platform for quantum computers and the next generation of ultra-fast and efficient electronics. Producing such materials in atomic scale, stacking the layers with frequent success rate and without introducing contamination and 'bubbles' [2] in the process is yet an obstacle in this field. Here we develop novel recipes for mechanical transfer method with Polycarbonate (PC). In this method we were able to manipulate the bubbles forming during transfer and create up to five layers of van der Waals heterostructure with atomically clean interface as large as 400 μm^2.

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Semi-Automating the Process of Microassembly with a Focus on Solarpede

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The Nexus Microassembly is a system used every day to assemble Micro-Electro-Mechanical Systems (MEMS). The microassembly consist of two manipulators, the PICO Pµlse by Nordson, three cameras, and three lamps. The goal of this project is to semi-automate the process of assembling MEMS with an early focus in a microrobot named Solarpede. The Solarpede is a solar powered micro-crawler with eight legs. The leg orientation varies but for the first semi-automated process the focus will be the design where the legs are in two parallel rows. The intention of the Solarpede is to operate in a micro-factory where it could either function as a conveyor or transportation system. The semi-automation of the Nexus Microassembly is being completed using National Instrument's LabVIEW. The semi-automation of the Solarpede and microrobots alike will allow users to assemble quicker, easier, and with more success. The program will have three main categories: vision, user prompts, and motion. The program will receive feedback from the top camera and interpret it with National Instrument's Vision Assistant. There will also be another camera on the back of the system to gauge movements in the z-direction. The vision feedback corrects components so that they are correctly in view for the user to interact with them. The program will prompt the user to check on its performance and ask for instruction on fine movements as necessary. In the future this program will be used as a template to automate the process for other MEMS.

Synthesis of SnO_2/SiO_2 composites as high capacity anode materials for LIB

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Demand for better performing electronics has in turn increased the demand for better performing Lithium ion batteries (LIB) (1). Although graphite as the anode material for LIB's has performed with great success for the past twenty years, it suffers from poor performance under high current densities and relatively low theoretical capacity (around 372 mAh/g) (1). Consequently, synthesis of SnO_2/SiO_2 nano-compositel is desirable as an alternative anode material due to its comparably higher capacity and structural ability to accommodate volumetric changes during the lithiation/ delithiation process. The goal of this project is to both synthesize the SnO_2/SiO_2 composite, and to characterize the sample's composition, morphology, and electrical properties. A successful synthesis of tin oxide material was obtained for the first part of this project. Currently, hopeful SnO_2/SiO_2 samples are being characterized to verify its composition, and the initial SnO_2 material is being used as the composite material in fabrication of electrode for coin cell testing.

References: (1) Naoki Nitta, Feixian Wu,Et al. Li-ion battery materials: present and future, June 2015, Materials Today.

Isotope Effects of Heavy Water on Fused Silica Solid-State Nanopores for Biosensing Purposes

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DNA sequencing using solid-state nanopores is generally hindered by high noise and low bandwidth for current devices. Previous work has demonstrated dramatic noise reduction by replacing silicon-based wafer for silica-fused wafers, allowing for higher bandwidth measurements. However, the current fabrication of fused silica nanopores has low yields due to wafer fragility during hydrofluoric acid (49% HF) wet etching. In this study, the fabrication of these devices was optimized to increase yield by up to 20%. Photolithographic masks were altered to limit the amount of SiO_2 being removed, hence increasing the wafer's robustness during wet etching. HF etching rate studies were also conducted to determine etching curves for silica fused wafers specifically; enabling users to calculate etching time, further lowering over-etched windows. To examine quality of nanopores, the devices were used for DNA translocation studies using 1 M KCl aqueous solution.

Nonisostructural Heteroepitaxial Growth of Potential p-Type Transparent Conducting Oxide $CuAlO_2$

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Copper aluminate, or $CuAlO_2$, belongs to the delafossites family of crystals and has a rhomboid structure. Theoretical predictions suggest that $CuAlO_2$ shows promise as a p-type transparent conducting oxide, a very rare characteristic in materials but potentially quite useful in applications such as liquid crystal displays or solar cells. Preliminary lattice parameter analysis suggests that c-face sapphire represents a good candidate for epitaxial crystal growth of $CuAlO_2$, despite sapphire being hexagonally structured. This project seeks to determine the best parameters by which $CuAlO_2$ can be heteroepitaxially grown on c-face sapphire using pulsed laser deposition and then perform an analysis on the lattice strains at the interface.

Strain Localization During Slow Strain Rate Testing of Sensitized Al-Mg Alloys

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Aluminum is a desired commodity for building vehicles, electronics, or other miscellaneous things. However, pure aluminum is soft and not as durable as needed for certain objects such as ships. Therefore, Aluminum-Magnesium alloys were introduced as a solution. These alloys help keep the lightweight features of aluminum while increasing strength, formability, and weldability. Yet, the magnesium segregation can lead to localized corrosion and stress corrosion cracking. This research is primarily focused on applications of Al-Mg alloys in saltwater environments, such as Navy ships, which are built using Al 5xxx alloys. This project investigated 20 samples of Aluminum 5456 that were broken into four subgroups which underwent different conditions to simulate the everyday stress and strain of a ship. The different conditions tested include sensitization, salt corrosion, and sensitization-salt corrosion. After enduring these conditions, the samples underwent a slow strain tensile test to further simulate the rough life of a ship. These tensile tests used a slow strain rate to ensure the observance of hydrogen embrittlement and stress corrosion cracking during the failure of the alloy. After failure, the samples' fracture surface was observed under the scanning electron microscope (SEM) to examine the strain effects on the metal. Aluminum alloys seem to experience brittle failure more often than ductile failure after exposure to nautical conditions, which is more catastrophic. Understanding the different fractures and cracks of the grain boundaries can help lead to the design of better materials that are more resistant to brittle failure and reduce the precipitation of magnesium.

Characterizing the Performance of Rapidly Degradable Polyaldehydes as Dry Developing Photoresist

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Demand for computer chips is increasing with the prevalence of small technological devices. Patterning of chips is enabled by photolithography, which requires the use of polymeric photoresist. Current photoresist development processes are solution-based and contain corrosive substances (tetramethylammonium hydroxide). The research presented here utilizes polyaldehydes, a class of rapidly-degradable polymers, as a positive tone photoresist that can be dry-developed by using mild vacuum or heating after exposure to photoacid generators (PAG). The result is a simpler development process and eliminates the use of solvent-based developer. Polyaldehyde degradation is enabled by their low ceiling temperature (T_C), or the equilibrium temperature between the monomer and polymer. Polymers based on ortho-phthalaldehyde ($T_C \sim$ -40°C), a homopolymer, p(PHA), and a copolymer with propanal, p(PHA-PA), were investigated as dry-develop photoresists. Characterization of photoresist performance was carried out by measuring contrast curves on 280 nm thin films to determine the sensitivity and contrast to exposures to 248 nm light. Development parameters were optimized through PAG content, post-bake temp and vacuum pressure. Best parameters for p(PHA) development were vacuum based to give a sensitivity of 7.5 mJ/cm^2 and a contrast of 2.7. Best parameters for p(PHA-PA) development were vacuum based to give a sensitivity of 12.5 mJ/cm^2 and a contrast of 2.02. The best features formed when exposed to room temp and pressures of 506 torr.

Self-hardening alginate gels for strengthening of soils

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Adapting microbially induced calcium carbonate precipitation (MICP) to soil provides a low-cost and sustainable solution to increase soil strength. The alternative conventional technology involves adding external chemicals to the

soil such as cement, which exerts negative pressure in terms of cost and efficiency. MICP uses the urease-producing microorganisms to deposit calcium carbonate (mainly calcite), which provides additional strength enhancement by curing cracks or by simply filling gaps. This is a promising technique that could be used for earthquakes and soil conservation. Additionally, the utilization of microbes could be enhanced by targeting specific spatial position within target soil. This is achieved by immobilizing the microbes on a gel that could be injected locally. Embedded in the gel, all required growth nutrients are included together with the microbes. Additionally, the required calcium ions are an integral component of this gel. Therefore, in this study, we focused on main two objects; (a) establishment of a robust method for calcium alginate gel capsulation in which all the materials (including *Sporosarcina pasteurii*) required for MICP were immobilized and (b) measuring the added soil strength after the application of this technology. As a result, precipitation of calcite was confirmed by X-ray powder diffraction (XRD), X-ray photoelectron spectroscopy (XPS), and optical microscope in multiple conditions. Moreover, the compression test confirmed the increase in soil strength over time. Based on the results, we expect that MICP using immobilization technology could be put to practical use as a useful ground improvement technology to obtain strength enhancement effect.

Agarose microchannels to study curvature effects in neuronal calcium signaling

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Various physical parameters in the cellular microenvironment such as substrate stiffness, surface topology, geometry, and confinement have been shown to influence cell migration, proliferation, and differentiation [1]. In the Kunze lab, we developed a method to fabricate a biocompatible substrate chip to allow neuronal cells to grow in confined curvatures using agarose micro-contact printing. For a high-resolution printing onto a petri dish, high aspect ratio microstructures were spin coated using a viscous negative photoresist. A single photolithography step was done to obtain the microstructures used for the neuronal-curvature study. The resin was spin coated (500 rpm for 10 s ramp-up speed; 3000 rpm for 30 s; 1000 rpm 10 s ramp down speed) to obtain a feature height of 50 µm. Next, pre-heated 3% (w/v) agarose hydrogel was pipetted onto a Petri® dish which was pre-coated with polyethyleneimine (PEI). Immediately after pipetting, a positive poly(dimethyl-siloxane) (PDMS) stamp, molded from the photolithography structures, was pressed firmly onto the agarose gel. Once cooled, the stamp was carefully removed, and disassociated neurons from rat cortical embryonic tissues were seeded to adhere between the soft-gel features. The agarose-based microchannels molded and adhered to the pre-coated petri dish and remained intact over a two-week duration in culture. Grown neuronal networks were stained with a fluorescent calcium marker (Fluo-4) and imaged for calcium signaling events. Our highly parallelized design allows for large scale pharmaceutical testing and neurobiological studies under high-throughput.

Reference: 1., Basso, J. et al., Physical Review E, 2019, 99, 022408.

Nanoresist: Engineering the Refractive Index for Photonic Devices

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The refractive index of materials is a critical parameter to designing various photonic devices and structures, such as resonator rings, emitters, waveguide, Photonic Wire Bonding (PWB) et al. Some complex 3D photonic structures can be fabricated by 3D laser lithography technology, where the photo resist will be polymerized under 2-photon absorption. Due to the viscus nature of resist (IP-Dip in our case), the refractive index of resist could be sensitive to multiple writing conditions, especially the exposure energy. The focus of this project is to (a) find an efficient method of creating samples that can properly be measured by spectroscopic Ellipsometry and other methods, and (b) observe the varying change in indexes among the change in dosage applied. This process is made possible using a rudimentary exposure tool constructed from an UV lamp and optical posts. Two methods were attempted in this project, (1) a thin film method, and (2) a block method using wells cut from PDMS (Polydimethylphenylsiloxane).

Scalable Production of 2D Transition Metal Dichalcogenide Based Electronics

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Reliable and scalable synthesis of two-dimensional (2D) transition metal dichalcogenides (TMDs) is attracting increased attention for their promise in large-scale atomically thin electronics, such as field effect transistors (FETs). These FETs can be adapted as biosensors, which can detect biological markers such as DNA and proteins, this aiding in early detection of disease. We have developed a universal method for the scalable growth of four 2D TMDs, MoS_2, $MoSe_2$, WS_2 and WSe_2, using spin coating-assisted chemical vapor deposition (CVD), for use in FETs. All four TMDs have were grown as high-density monolayer flakes with sizes ranging from 10-100 µm. Once grown, TMD flakes were transferred to FET arrays as gap materials, to fabricate large-scale TMD-based FETs. Single TMD-based FET devices were also produced, which were then functionalized for use as biosensors using a novel universal functionalization method.

A Next Generation Vaccine Adjuvant: *in vivo* Evaluation of CpG DNA Complexed with Calcium Phosphate as a Vaccine Adjuvant

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One of the key biomedical developments of the 20th century was massive growth in the development and deployment of vaccines. One element in increasing the effectiveness of vaccines was the discovery of certain substances that could be used as vaccine adjuvants, improving the immunostimulatory effects of the vaccine. Recently, a new type of adjuvant, referred to as CpG DNA, has shown promise as a basis for a next generation vaccine adjuvant. Complexing this CpG DNA (K3) with calcium phosphate (CaP) nanoparticles leads to an increase in both ThI and ThII-type humoral immunities, as well as a generation of cellular immunity. Since CaP has an adjuvant effect in and of itself, our main question is whether K3 complexed with CaP is a more effective adjuvant than K3 mixed with CaP. To test this, we inoculated murine models with OVA cancer vaccine under four conditions: no adjuvant, K3, K3 complexed with CaP (K3/CaP), and K3 mixed with CaP (K3+CaP). The immune responses were determined by sampling blood and analyzing with FACS and ELISA. The results indicated that while K3/CaP and K3+CaP produce similar humoral immunity responses, K3/CaP is a more effective vaccine adjuvant for the purpose of promoting cellular immunity.

Structural Characterization of 2D Layered Complex Hetero-Ion Systems

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The motivation behind this project is to study the structure of complex hetero ion based lamellar materials and their physical properties, including ferroelectricity and ferromagnetism, at the 2D limit. By mechanically exfoliating bulk single crystals of $CuInP_2S_6$, $CuCrP_2S_6$, and $CuCrP_2S_6$, a top down approach is used to obtain flakes that are as thin as possible. By isolating a monolayer of these materials, future studies will be conducted to probe for the existence of subnanometer ferroelectric, ferromagnetic, or magnetoelectric multiferroic responses from each respective material systems. Furthermore, studies on heterostructures formed from stacking different monolayers of material in order to study the coupling between different layers are also considered. In hope of its success, we can formulate a device that can take advantage of its magnetoelectric coupling in applications of spintronics and capacitors for more advanced computing.

Using Atomic Force Microscope (AFM) and Raman Spectroscopy, I developed a system to measure the thickness of flakes and to correlate them to Raman spectra and optical images. Despite its challenges, I have successfully measured a range of flake thickness that correlates to a trend in the intensity of the Raman spectra. This allows us a way to identify thin flakes of materials to pursue future studies on the multiferroic character of these materials systems at the 2D limit.

Broadband high-efficiency and polarization-insensitive metalens

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Comprised of subwavelength-spaced phase shifter nanofins, metasurfaces are capable of manipulating the amplitude, phase, and polarization of light. In effect, metasurfaces allow for the shrinking of conventional optical components into planar structures and nanoscale devices. However, efficiency limitations are an obstacle for the applicability of metasurfaces as designs are constrained by the limited selection of nanostructures. Here, we utilize coupled and anisotropic nanofins as building blocks to realize broadband high-efficiency and polarization-insensitive metasurface gratings. This is made possible because the building block enables high tunability of design parameters, resulting in about 20 thousand different nanostructure combinations. Furthermore, we restrict the rotation angle to 0 or 90 degrees to achieve polarization-insensitivity. Preliminary results from this project include the simulation of a metasurface grating with an average of about 85% grating efficiency over most of the visible spectrum, from 450 nm to 700 nm wavelengths. We plan to further demonstrate other broadband high-efficiency metasurface elements. The high-efficiency surfaces have extensive and promising applications in microscopy, imaging, and other technologies.

Thermal and Photo-oxidative Degradation of Commercially Available Oxo-degradable Plastics

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The occurrence of microplastics (< 5 mm) is an issue of global concern and poses significant risks to aquatic life, ecosystem, and human health. Oxo-degradable plastics are developed and marketed as one of the eco-friendly solutions to persistent plastic pollution in the environment. By incorporating metal-based pro-oxidants, the oxo-degradable plastics are designed to undergo fast degradation and fragmentation upon exposure to light or heat. However, the accelerated fragmentation processes are poorly documented and may cause greater microplastic accumulation in the environment. To understand the degradation of oxo-degradable plastics, we compared commercially available oxo-degradable plastics to regular plastics with respect to metal additive content, degradation rate, and microplastic production. Oxo & regular versions of polypropylene (PP) straws, high-density polyethylene (HDPE) grocery bags, and low-density polyethylene (LDPE) wrapping films were exposed to three different degradation conditions including UV photo-oxidation, outdoor weathering, and thermal treatment. X-ray fluorescence (XRF), inductively coupled plasma mass spectrometry (ICP MS), and Fourier-transform infrared spectroscopy (FTIR) were used for characterization. The FTIR results indicated that the oxo-degradable plastics did not degrade at an accelerated rate compared to similar regular plastics despite having higher levels of transition metals. Only the UV treatment resulted in significant microplastics production; very little were produced from oven or outdoor treatments. Longer study time is needed for examining microplastic production under environmental conditions.

Microfluidic Chip Manufacturing for Point of Care Sepsis Diagnosis

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Contributing to nearly 250,000 deaths per year in the US alone, sepsis is a life threatening condition that alters the body's immune response to infection leading to organ dysfunction. Death from sepsis can occur within hours, however the current diagnostic method for sepsis includes non-specific monitoring of organ dysfunction with a cell culture, which can take multiple days. The goal of the project is to create a point of care microchip that can provide an accurate diagnosis in 30 minutes or less based on measuring the level of expression of white blood cell antigens correlating to the presence of sepsis. The device consists of a lysing process that removes red blood cells while preserving white blood cells, and antibody-coated micropillars that capture white blood cells containing the target antigens. Recently, the focus of the project has been to refine the red blood cell lysis, with a secondary goal of redesigning the pillar arrangement to maximize cell capture. Using a lysing buffer of formic acid and saponin and a quenching buffer of phosphate buffered saline and sodium carbonate, we have been able to achieve up to 99% red blood cell lysis while maintaining less than 10% white blood cell lysis in on-bench experiments. Initial testing of cell capture on the pillars has resulted in a new pillar design by reducing the number of pillars from 400,000 to 30,000, thus increasing the ease of imaging, manufacturing, and flow. On-chip red blood cell lysis and cell capture are currently being refined and tested.

Characterization of *in situ* TEM heating holders using silver nanocubes

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In situ transmission electron microscopy (TEM) is the real-time high resolution imaging of specimens in dynamically changing local environments. In order to obtain reliable *in situ* heating measurements, we need to calibrate the system, in particular, to understand the temperature reproducibility and uniformity of the holders used. Here we describe the characterization of heating approaches by studying the sublimation of silver nanocubes. Silver nanocubes were chosen as a model system because they are commercially available, they are non-toxic, their sublimation temperature is within the range of the heating holder and they provide high contrast in TEM images. We heated the nanocubes to a nominal temperature of 400°C to thermally decompose the capping ligand surrounding each particle, then raised the temperature to ~800°C and recorded the sublimation processes via fast acquisition TEM imaging. We observed the particles getting smaller over time, which we attribute to sublimation. The size of each particle before sublimation was measured and compared to the time taken for sublimation; a regression trend was observed demonstrating that larger particles take longer to sublime. Through performing multiple measurements, we obtained data on the reproducibility and temperature uniformity of the holder(s). We assessed whether the Kelvin model could be used to extrapolate the sample temperature from these experiments. This work will improve the accuracy of future experiments performed with these heating holders.

Developing Microfluidic Devices for Assisted Reproductive Technologies

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The gaining popularity of Assisted Reproductive Technologies (ART) such as In Vitro Fertilization (IVF) and Intracytoplasmic Sperm Injection (ICSI) calls for the introduction of more affordable and less tedious processes rather than the typical manual operations. In order for ICSI to occur, the Cumulus Oocyte Complexes (COCs) retrieved from the ovaries must be processed in order to remove the tightly-packed cumulus cells surrounding

them. As of yet, this tedious and unstandardized process is being done manually by skilled embryologists, which result in variability and unavailability. The focus of this project is to develop microfluidic devices to denude the COCs for ICSI in order to reduce the tyranny of manual operations and push towards automated reproducible operations. These microfluidic devices are fabricated through conventional PDMS microfluidic processes and tested using automated magnetic pumps controlled by a microcontroller. Currently, actual microfluidic devices were developed and were successfully tested using particles similar to COCs.

Determining Origins of Water Contamination in Atomic Layer Deposition Oxide Films Using Deuterated Water

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Atomic Layer Deposition (ALD) is a vapor deposition technique that can precisely deposit conformal thin films of materials that have applications in creating high κ-dielectric layers, insulators, and conductive structures. Although such ALD produced materials show promise in the semiconductor industry, water contaminates from ALD may change the electrical and optical properties in films. In order to relatively quantify water contamination in ALD films from the ALD process chamber, pure 2000 Å thick films of HfO_2 and Al_2O_3 were grown under high and low temperatures using deuterated water (D_2O) as the initial precursor instead of water (H_2O). D_2O acts as marker that shows water contamination originates from the ALD process chamber. Any H_2O present in the films, shows that water contamination originates from external sources such as the atmosphere. Fourier-transformed infrared spectroscopy (FTIR) and atom probe tomography were used to differentiate between any D_2O and H_2O present on or in the films.

Time and Frequency Domain Modeling of Thermo-Plasmonic Effects

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Silver nanostructures exhibiting plasmonic behavior are modeled using time and frequency domain simulations. Light propagates towards the nanostructure and the transmission and reflection of the light is computed by these full-wave simulations. This was done in frequency domain, using a finite element model, then in time domain, using a finite difference time domain model. The time domain results were verified by the frequency domain results. Next, the thermo-plasmonic effects of the material were investigated, where thermal effects are induced due to the incident electromagnetic radiation. This was again done in both time and frequency domain. For frequency domain the effect that different frequencies of light have on the material's temperature are investigated, as well as the effect of the intensity of the light. In time domain a two-temperature model (TTM) is implemented. Here the electronic temperature and lattice temperature are separated, in order to see how a femtosecond laser pulse causes the material to heat up at fast and moderate time scales. The results between time and frequency domain matched up well for the reflection and transmission coefficient. The heat maps for both time and frequency domain also match up well. The results for the two-temperature model are still underway and will be presented here.

CO Detection through Sum Frequency Generation (SFG)

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The surface chemistry of adsorbed CO by dissociated CH_3OH at polycrystalline Pt electrode/electrolyte interface was studied using picosecond time-resolved sum frequency generation (TR-SFG) spectroscopy. With an electrolyte solution of 0.1 M $HClO_4$/0.1 M CH_3OH a peak was observed about 2060 cm^{-1} at the platinum electrode interface

from 100-350 mV. This peak indicates that CO adsorbed on the Pt surface from dissociated CH_3OH. For voltages up to 200 mV, a peak shift of about 60 cm^{-1}/V was observed, which is due to the weakening of the Pt-CO bond. The voltage was increased until CO was no longer adsorbed onto the surface. Once the voltage was dropped to 100 mV again, a re-adsorption peak of 2046 cm^{-1} was observed. An infrared pulse (1064 nm) irradiated the surface and caused the intensity to increase briefly, which would suggest that additional CO adsorbed onto the surface during the sharp intensity increased.

Random Access Memory using Perovskite Materials

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Project is centered on creating a Resistive Random Access Memory (R-RAM). Units of this memory device will comprise of memristors whose geometry are similar to a capacitor. Lanthanum Aluminate and Strontium Titanate ($LaAlO_3/SrTiO_3$ or LAO/STO) known for their conducting interfaces are two perovskite materials used as the dielectric layer. Simplified chips were microfabricated to study the electrical properties of this new device. After fully characterizing the memristors, the next step would be to look into increasing the memory density on a single polycrystalline silicon wafer by way of conducting scanning probe lithography.

Effects of Metal Evaporation on 2D Semiconductor-Metal Contacts

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Transition metal dihalcogenides (TMDs) have emerged as an important class of semiconductor materials in electronic and optoelectronic devices, most notably due to their atomic thickness and direct band gap that emerges when stripped down to monolayer thickness. These devices rely on metal-semiconductor contacts in their device design and decades of research has been devoted to perfecting these contacts. This project examines how commonly used fabrication techniques atomically affect these contacts. Contacts were fabricated by two separate methods: (1) direct exfoliation of a TMD onto a metal substrate and (2) evaporation of a metal onto a TMD. Once fabricated, scanning probe techniques were used to evaluate these samples. The current-voltage (I-V) characteristics for the two techniques showed different results, signifying a change in transport mechanism and thus, the nature of the contacts. In addition to changing the type of fabrication, the metal used in the contact was also varied for a comprehensive study.

Improving the Reliability and Capability of PARADIM's MBE

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Molecular beam epitaxy (MBE) is a thin film growth method which may be thought of as atomic spray painting. The focus of this project is to design various hardware improvements to this MBE system by using Solidworks and knowledge in mechanical design. Therefore, whenever working on any specific design, aspects such as practicality, machinability, and cost must continuously be accounted for. Some of the designs accomplished throughout this project were new differential pumping sleeves and centering pieces with longer life spans or custom crucibles composed of new materials. In addition, PARADIM users will now be able to use MBE to deposit material in useful patterns such as gold contacts in the corners of the thin films. This is now a possibility due to a shadow mask that was designed to work in conjunction with the current system. Currently, the completed designs are either in the process of being manufactured by outside vendors or we are in the process of searching for an outside vendor.

Enhancing Cell Death Using Targeted Photoactivable Multi-Inhibitor Liposomes

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Chemotherapy is a standard treatment for a majority of cancers diagnosis. This treatment method works by injecting the body with toxic chemicals, in hopes of obliterating the tumor. In the midst of doing so, a large number of healthy cells are killed because the chemotherapy drugs cannot differentiate between the healthy and tumor cells. Common side effects of chemotherapy include nausea, vomiting, and hair loss [1]. One method of alternative cancer treatments, formerly known as photodynamic therapy (PDT), utilizes physics and chemistry to aid in drug delivery. This method begins with the injection of photosensitizing agents so they can be incorporated into the cells. Although the photosensitizers (PSs) are incapable of distinguishing between the healthy and tumor cells, it has been reported that the PSs are retained in tumor cells for a longer period of time when compared to healthy cells [2]. After a pre-determined incubation time from the initial injection of the PSs, the tumor is exposed to light via an endoscope and fiber optic cables [2]. "Irradiation at an appropriate wavelength leads to an interaction between the photosensitizing agent and oxygen in tissues, resulting in formation of reactive oxygen species (ROS) that can initiate cell death process" [3]. Further efficacy can be achieved through the targeting of subcellular organelles that are important to cell growth and death such as the mitochondria, lysosomes, and endoplasmic reticulum [4]. Our research suggests that targeted photoactivable multi-inhibitor liposomes (TPMIL) provides us with the means necessary to achieve this efficacy.

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Synthesis of CuZn Alloy Films through Electrodeposition

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Porous copper current collectors are a promising method of inhibiting dendrite growth in lithium-metal anodes. Current collectors reduce dendrite growth by preventing regions of critical charge density on the surface of the anode. However, synthesizing current collectors via the electrodeposition of pure copper only leads to high porosity in relatively thin films (~5 µm). The focus of this project is to synthesize and dealloy CuZn alloy films in order to (a) observe the influence of deposition conditions on the composition and morphology of the deposited films and (b) improve the thickness and porosity of the resulting copper films. CuZn alloys were synthesized from a citrate bath with the addition of polyethylene glycol (PEG) and chloride ions in the first part of this project. The alloys were then electrochemically dealloyed to produce porous copper films. Agitation of the electrolyte during electrodeposition lead to a substantial decrease in electrode potential and resulted in a thick (~26 µm) and highly porous (~80%) film. Films synthesized employing these methods will be filled with lithium and tested as anodes to determine their battery performance.

Fabrication and Characterization of Vitamin-C Reduced Graphene Oxide Neural Microelectrodes

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Electrode arrays can be used to study neural microcircuits from the brain surface, to better understand the mechanisms underlying neurological disorders such as epilepsy. Graphene is an ideal two-dimensional nanomaterial for such arrays, as it is flexible, highly conductive, and biologically inert. The reduction of solutions-processable graphene oxide (GO) into graphene-like sheets of reduced graphene oxide (rGO) is a scalable, high-yield process for realizing neural arrays that is compatible with microfabrication techniques. However, typical GO reduction methods, such as exposure to hydrazine or other harsh acids, are toxic to handle or incompatible with the polymers commonly used for microelectrode encapsulation. To address these shortcomings, we have investigated the safer, fully biocompatible reduction of GO using *l*-ascorbic acid (vitamin-C). Multichannel neural arrays, microfabricated using facilities in the University of Pennsylvania's Singh Center for Nanotechnology, were characterized using electrochemical impedance spectroscopy (EIS) and exhibited an impedance of ~143 ± 40 kΩ at 1 kHz (n = 11 contacts). These results indicate that the vitamin-C reduction method is a safe, scalable, and reliable route for realizing biocompatible rGO neural microelectrodes.

Elucidating the Shape of the Quantum Tunneling Barrier in Self Assembled Monolayers

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Advancements in nanofabrication have led to the manufacturing of conventional microcircuit components (transistors, capacitors) on a scale small enough to be subject to quantum phenomenon such as quantum tunneling, which gives rise to leakage currents in these systems. The field of molecular electronics is focused on designing microcircuit components from organic molecules, and controlling quantum tunneling by modifying their molecular structure. This work studies the change in barrier height and barrier shape of molecules with different terminal groups, dipole moments, and bottom electrodes (Ag and Au). For this work we use a junction developed specifically for this purpose (the so-called "*EGaIn*" junction). This junction has three parts: i) a bottom electrode made of flat gold or silver; ii) a self-assembled monolayer (SAM) of an organic compound; iii) a top electrode made from a compliant structure composed of a drop of liquid eutectic gallium-indium alloy (EGaIn), covered by a thin conducting film of gallium oxide. In use, this drop is formed into a conical tip with a macroscopic contact area with the SAM of ~100 μm^2. We find that dipole, terminal group, and bottom electrode all influence the shape of the tunneling barrier and can be used to control the voltage dependent tunneling characteristics of molecular junctions.

Process Characterization of the Microscale Deposition Tools

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Recent advancement in 3-D printing technology, such as Ink and Aerosol Jetting, introduced novel tools enabling fabrication of the multiscale structures (submicron to millimeter size) which could be applied for the assembly or integration of the Micro-Electro-Mechanical Systems (MEMS). In this study we present results of the Ink and Aerosol Jet printing process characterization realized with the help of the Nordson EFD PICO Pulse and Optomec

Aerosol Jet Print Engine. PICO pulse system allows controlled and precise deposition of the fluid at nano-Liter scale. This property could be utilized for controlled deposition of the viscose UV curable adhesives which are used for the MEMS robots assembly. The Aerosol Jet system enables printing of the 40 -100 micron features with sub/few micron thickness e.g. conducting lines and patterns. This has a wide range of possible applications that include flexible electronics and sensors which can be manipulated to meet the user's specific requirements. For future automation of the PICO Pulse and Aerosol Jet printing processes and instrument integration with other tools (e.g. Nexus Multi-Scale Robotics System) a number of experiments were designed and conducted in order to achieve printing process control and formulate specific recipes.

Photonic Wire Bonding by 3D Laser Lithography

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Photonic systems use light (photons) to transmit signals, which can travel faster than electrical systems. Photonic systems are composed of light sources, waveguides, receiver/detector, and other devices such as optoelectronics, photovoltaic cells, and optical amplifiers. Typically, these components are separated from one another and need to be interconnected by various coupling methods. Signal loss from coupling mechanisms has led to integrated photonic systems where the photonic components are fabricated as a single integrated structure onto a substrate surface with a significantly reduced need for off-chip coupling. Regardless of the tremendous progress of photonic integration, the increase of on-chip integration density has made the fabrication and manual alignment of coupling mechanisms between tapered structures more challenging. A breakthrough in optical packaging and interconnection technology is photonic wire bonding (PWB) based on 3D laser photolithography. Different from metal wire bonding in electrical systems, PWB is printed using a transparent polymer to create accurate waveguides that act as couplers to bridge the gaps between components in a photonic system. Taking advantage of Nanoscribe, a 3D laser lithography system based on two-photon polymerization (TPP), we can design and fabricate a complex structure that can taper and bend. The focus of this project is to fabricate a PWB using 3D laser lithography so that we can (a) create a single-mode fiber-to-chip and fiber-to-fiber interconnection and (b) study the total signal loss due to light refractions for both insertion and transmission.

Examining the Link Between Mechanical and Thermal Properties in Crystals

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Materials that exhibit anomalous thermal or mechanical properties, like negative thermal expansion and negative linear compressibility, allow for the design of composite materials with tailored properties. The need for tailored thermal and mechanical properties is necessary in nearly every engineering application since devices must be robust to temperature and pressure variation. While many materials exhibit negative linear compressibility, there remains a need for material options that show negative thermal expansion. Unfortunately, predicting negative thermal expansion is a cumbersome task. Most research has focused on a calculation strategy that builds the thermal expansion from the calculated linear compressibility and Grüeisen parameters—a measure of how the vibrational free-energy changes with strain. A material is selected for further study if the Grüeisen parameters are *negative*. Recently, it was rediscovered that materials with *positive* Grüeisen parameters can exhibit negative thermal expansion if they also have negative linear compressibility.

The focus of this project is to examine the relationship between negative linear compressibility and negative thermal expansion in materials with positive Grüeisen parameters. Our survey of the existing literature found nineteen materials that exhibit both negative thermal expansion and negative linear compressibility. Eight of these materials had detailed structural information that were used for comparison. Silver hexacyanocobaltate, silver tricyanomethanide, and $KMn[Ag(CN)_2]_3$ all share a similar "hinge-like" bond layering along the c-axis, making them a useful touchstone for theoretical consideration. First principle calculations of their compressibility and Grüeisen parameters are being explored in these materials for further insights.

Optimization of Large-Scale Imaging with Scanning Electron Microscopy

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The spatial resolution capabilities of modern electron microscopes have improved far beyond that of light microscopes, which are limited by the wavelengths of visible light (Heintzmann and Ficz, 2006). Electron microscopes can be categorized into scanning electron microscopes (SEM) and transmission electron microscopes (TEM). While TEMs are optimized for high magnification imaging, SEMs can image at both low and high magnifications. Large-scale imaging techniques at the tissue and cellular scale are especially helpful in capturing cell morphology, which can be used in applications such as cancer research and drug development (Sassa-deepaeng et al., 2017, Bazant et al., 2016). With SEM, smaller regions of interest (ROI) can be identified from larger area screens, bridging the magnification gap between light microscopy and TEM. Electron microscope image quality is dependent on both sample preparation and instrumental parameters. In the current experiment, large-scale SEM image quality was optimized by adjusting the following instrumental parameters: acceleration voltage, spot size, dwell time, and working distance. Using ImageJ/Fiji and DigitalMicrographTM, image quality was measured with the relative signal-to-noise ratio (SNR) and a Fourier-based method of estimating spatial resolution (Schindelin et al., 2012, Mitchell and Schaffer, 2005, Sage, 2003, Joy, 2002). A non-linear relationship between SNR and spatial resolution and acceleration voltage, spot size, working distance, and dwell time was found, with slight differences between imaging at low and high magnification. Implementation of machine learning based on the optimization of instrumental parameters achieved in the current experiment may make SEM imaging more accessible to future researchers.

Rapid Photo-Catalytic Oxidation of Dissolved Manganese with TiO_2

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Manganese(III/IV) (hydr)oxides (hereafter Mn oxides) occur ubiquitously in terrestrial and marine systems, and play crucial roles in natural electron and element cycles. However, the understanding of their occurrence is limited due to the slow oxidation of Mn^{2+}(aq) to Mn(IV) which precedes the formation of Mn oxides. Through the photocatalytic process with TiO_2 (the 9^{th} most abundant compound in the Earth's crust), we found very fast oxidation of Mn^{2+}(aq) to Mn(IV). The reaction rate is even much faster than microbial processes, which has been believed to be the primary mechanism for the oxidation. We studied the oxidation process under a variety of conditions, such as different TiO_2 structures (anatase vs rutile), different solvents (saltwater vs freshwater), and different atmospheric conditions (open air vs nitrogen). These analyses show that the fast photocatalytic oxidation occurs primarily due to direct electron transfer between Mn^{2+}(aq) and photo-excited TiO_2. This understanding will enable us to explain the abundance of natural Mn oxides on rock surfaces. In addition, because the redox process of Cr and Tl, which are newly emerging paleoredox proxie, is significantly governed by Mn oxides, understanding of Mn oxide formation will help to calibrate the redox proxy systems for oxygen evolution on early Earth.

Development of Thermally Actuated Tunable Adhesive Structures

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Structures with switchable adhesion have applications in robotics and manufacturing. Here, fabrication techniques to make thermally-actuated tunable adhesive structures are investigated. The devices consist of thin-film microheaters that transfer energy to adhesive pillar structures causing local heating in the center pillar that leads to expansion in the PDMS and delamination. Excimer laser micromachining was used to create adhesive pillar structures with complex geometries out of polydimethylsiloxane (PDMS). Two types of structures were micromachined, simple pillars, and structured pillars. The simple pillar structures that were fabricated than tested are capable of adhesive forces up to 42 mN, for a pillar with a radius of 500 µm, which is an adhesive stress of 52kPa. These simple pillar structures are a proof of concept for the more complex tunable adhesive that make use of structured pillars. The heaters were fabricated using photolithography, and lift off, in which we deposited 250 nm of Au to function as the conductive material of the heater. Six different designs of heaters where made for testing to see which creates a low adhesion state that will require the smallest force for delamination.

Patterned Co-cultures of Stellate Cells and Hepatocytes using Nano-structured Polymer Film to Study Cell-Cell Interactions in the Liver

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Liver fibrosis is a disease characterized by liver stiffening as a result of chronic liver damage. This stiffness is driven by the interaction between hepatocytes and stellate cells. Current methods to model hepatic fibrosis *in vitro* fail to recreate the hepatocytes-stellate cell interactions in play in the liver during physiological and pathological liver environment. There is a need for for an effective platform to study the role of cell-cell interaction in the progression of liver fibrosis. Here, we aim to engineer patterned co-cultures of RLW (hepatocytes) and LX2 (stellate cells) cells on tissue culture polystyrene (TCPS), which had been coated with alternating polyelectrolyte bilayers of poly(diallyldimethylammonium chloride) (PDAC) and polystyrene sulfonate (SPS). These co-cultures provide an effective method that allows for direct contact between the cells, which current methods fail to replicate. We also cultured patterned monocultures on coated TCPS as well as 2 kPa (healthy) and 25 kPa (fibrotic) stiffness surfaces made from Polydimethylsulfonate (PDMS), in order to recreate liver stiffness at different stages of the progression of liver fibrosis. We found that RLW cells readily formed patterns on TCPS as well as 2 kPa and 25 kPa stiffness surfaces. Both RLW and LX2 Cells displayed distinct morphological differences between the different surfaces. While LX2 cells remained quiescent on the 2 kPa surface they were activated on the 25 kPa surface and TCPS, becoming much larger and reproducing rapidly. These results demonstrate that these models can be used to display disease states across the progression of hepatic fibrosis.

Floating Zone Crystal Growth and Characterization of Boron Carbide

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Boron carbide is an inexpensive, light weight ceramic with potential for applications in body armor, high temperature thermoelectrical conduction, ionizing radiation shielding, and neutron detection. The rhombohedral crystal structure of the material means that mechanical, electrical, and physical properties may vary along differing crystallographic orientations. Thus, measuring such anisotropic properties requires the use of single crystals. Single crystals of boron carbide are non-trivial to grow; thus, few studies have been conducted measuring the properties

of this material across its varying orientations. Single crystals of boron carbide were grown via the floating zone method utilizing PARADIM's laser diode floating zone furnace. From Laue diffraction, we identified several distinct rhombohedral crystal directions, which has allowed and will continue to allow us to measure orientation dependent physical properties.

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Growth and Characterization of 2D Transition Metal Dichalcogenides

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Uniform monolayer growth of 2D Transition Metal Dichalcogenides, (TMDs), over large areas offers the possibility for great advancements in the technologies of nanoelectronics, optoelectronics, and valleytronics. Physically robust at three atoms thick, TMDs with direct bandgaps make both flexible and transparent devices more possible than before. This project's focus is to find suitable conditions for monolayer growth of molybdenum based TMDs over a three-inch wafer using Metal Organic Chemical Vapor Deposition, (MOCVD). Changes in the growth chamber's flow rates, temperature, and internal arraignment are used to find reproduceable recipes for MoS_2 and $MoSe_2$ monolayer growth. TMD films are characterized using optical microscopy, scanning electron microscopy, and Raman spectroscopy to determine film thickness, coverage, and grain size. $MoSe_2$ films have ~90% surface coverage with ~6 µm grains but do not offer a large enough uniform growth area for a full wafer trial. MoS_2 films have areas of up to ~95% coverage with grain sizes of ~5 µm, attempts at full wafer growths have been made with limited success.

Exosome Loading of Molecules using Microfluidic Devices

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Exosomes are extracellular vesicles that include proteins, mRNAs, miRNAs and DNAs derived from cells. They are also found in biological fluids including blood, urine and cerebrospinal fluid. Because of their high biocompatibility and low toxicity, exosomes are expected to be used as a carrier for drug delivery. However, state-of-the-art exosome loading methods, such as the electroporation and chemical reagent approaches, are expensive and time consuming. In this work, we propose a novel exosome loading method that uses a microfluidic device in the aim of reducing the cost. The proposed approach utilizes shear stress of surrounding flow in the microfluidic device and loads specific molecules into the exosomes. Because both exosome and fluorescein have negative charges, as a loading molecule, we choose fluorescein, and thus we can ignore aggregation via electrostatic interaction. In order to verify the proposed approach, we performed the loading of fluorescein into the Jurkat-cell-derived exosomes. After conducting ultrafiltration to remove the unloaded fluorescein from the solution, we measured the fluorescence intensity and confirmed the exosome loading of fluorescein. After the maximization of the shear stress by optimizing the ridge gap, the total length, and the flow rate of the device, we found that the optimal ridge gap is 2.5 µm, the total length is 4.1 mm, and the flow rate is not a big factor. The proposed method takes 99% less cost to load fluorescein into exosomes. To our knowledge, this is the first work that uses a microfluidic device to load specific molecules to exosomes.

Characterizing the Nanoscribe Photonic GT System for Fabricating MEMS Bistable Structures

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In this research project, we explore if the Nanoscribe Photonic GT system can be used to fabricate bistable MEMS (microelectromechanical systems) structures. Bistable MEMS devices typically consist of thin diaphragms and cantilevers, which require precise control of its micro- and nano-scale structural features to function properly. They exhibit the unique ability to transition into 2 distinct mechanical states and remain there indefinitely, thus making them candidates for many no/low power applications, such as mechanical memory and no power sensors. The Nanoscribe Photonic GT system is an advanced 3D printer that uses a two-photon polymerization process to print three-dimensional features as small as 160nm. Therefore, it should be a viable manufacturing candidate for quickly producing such bistable devices. In this research, we explored various design considerations, print job preparation strategies, printer settings, printing materials and printing substrates. Designs were printed on silicon wafers, ITO covered glass, and glass. For the cases of silicon and ITO covered glass, we used IP-S photoresist and a 25X objective, as recommended by the vendor. For glass, we used IP-Dip resist and a 63X objective. Various printer settings were examined in each case. The less viscous IP-Dip resist proved problematic as many of the thin overhang structures of the bistable MEMS device failed by collapsing. We obtained better results with the thicker IP-S resist and the 25X objective, however this also had significant limitations. This presentation will review the parameter space we examined, the obstacles we faced, and show our novel results.

Area-Selective Deposition to Enable Single-digit nm Fabrication

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As semiconductor manufacturing approaches single-digit nm feature sizes, there is an increasing difficulty in reliably patterning critical device features. Conventional top-down techniques suffer from issues with alignment of device features during the manufacturing process. Area-selective deposition (ASD) seeks to remedy this by a bottom-up technique, selectively depositing films only on defined growth areas and not on non-growth regions, creating a "self-aligned" feature. We produce line and space patterned wafers of metal and dielectric, copper and silicon dioxide in this study, to serve as a substrate for ASD experiments. We use various characterization techniques, such as optical microscopy and scanning electron microscopy (SEM), to evaluate our wafers. We also discuss intended uses of these wafers in ASD experiments.

Synthesis and Characterization of Functional Transport Materials

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Understanding the intricacies of electronic phenomena in new functional transport materials will give greater insight into fundamental understandings and applications of materials. The materials investigated have interesting properties leading to applications in quantum computing in the case of topological Kondo Insulator candidate YbB_{12} and waste heat recovery for the new thermoelectric $Cu_2GeZnTe_4$. Previous reports have shown YbB_{12} as having quantum properties, but with the synthesis of this compound being difficult, these quantum phenomena could possibly be attributed to material defects rather than the intrinsic properties of the YbB_{12}. By using PARADIM's Laser Diode Floating Zone Furnace to grow single crystals of the Kondo Insulator, the instrument allows for a well defined heating profile for a higher quality synthesis. The quality of the material can be assessed

through X-ray diffraction and Laue measurements and the materials quantum properties tested through various electronic and magnetic property measurements. The desired chemical composition of $Cu_2GeZnTe_4$ was determined using a database called TE Design Lab, which consists of theoretical and experimental data of potential quality thermoelectric materials gathered by Dr. Eric Toberer. Because of the low temperature barrier for synthesizing the isostructural compound to the Cu_2-II-IV-VI_4 family of thermoelectrics, the $Cu_2GeZnTe_4$ is synthesized and densified using spark plasma sintering to further determine its thermal and electrical conductivity.

Growing 2D Transition Metal Dichalcogenides

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Monolayer transition metal dichalcogenides (TMDs) are three atom thick materials that are ideal candidates for electronic and optoelectronic devices such as photodetectors and light emitting diodes. TMDs are also unique for their electronic properties including the large excitonic effect, indirect-to direct bandgap transition, piezoelectricity, and valleytronics. Metal-organic chemical vapor deposition (MOCVD) is on the forefront in producing high-quality large scale TMDs. The focus of this project was to develop reproducible MOCVD recipes for uniform monolayer tungsten disulfide (WS_2) and tungsten diselenide (WSe_2). To achieve this goal I optimized the growth conditions including growth temperature, flow rates of the precursors, and growth time. Optical microscopy (OM), scanning electron microscopy (SEM), and Raman spectroscopy were used to characterize the TMDs (e.g. grain size and formation of multilayers). Currently a reproducible recipe has been developed for synthesizing continuous films of monolayer WS_2 with a grain size of ~10 µm, while the recipe for WSe_2 is still under development.

Fabrication of Sub-10 nm Nanopore Materials via Block Copolymer Self-Assembly

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The microphase-separated structures produced by the self-assembly of the block copolymers (BCPs) are of great interest for the application in the next-generation lithographic technology to achieve the sub-10 nm nanofabrication. Among the various kinds of nanostructures, the cylindrical structure is a promising template to fabricate the nanopore materials, such as nanofilteration menbranes. The goal of this project is to develop the protocols to obtain the nanopore materials via BCP self-assembly. Firstly, polystyrene-*block*-poly(methyl methacrylate) (PS-*b*-PMMA) toluene solution was spin-coated on the random copolymer polystyrene-*r*-poly(methyl methacrylate) (PS-*r*-PMMA) (PS 60 wt%) grafted onto the SiO_2 or Al_2O_3 layers on the Si-substrate, giving the uniform BCP thin films. The self-assembled cylindrical nanostructure was then successfully obtained by the thermal annealing under the vacuum, and the p.m.MA portion was removed using O_2 plasma. SEM observation revealed that the nanopore structure was clearly fabricated on the BCP thin film. We are currently trying to transfer the obtained nanopore pattern to the underlying SiO_2 and Al_2O_3 layers as well as Si-substrate.

High Density Quantum Dots for Solar Cell Applications

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Traditional solar cells consist of semiconductor material and can absorb photons from the sun that have energy equal to or greater than their bandgap. Introducing intermediate states to a solar cell allows for photons with lower energies to also be absorbed. One way to fabricate intermediate band solar cells is by embedding quantum dots (QDs) into the cell, which creates discrete states due to QD confinement properties. Since the absorption coefficient is proportional to the number of QDs, higher densities of QDs result in more photons being absorbed and, therefore, improved efficiency.

We were able to grow high density QDs by droplet epitaxy. Unlike Stranski-Krastanov growth, the most common method for growing QDs, droplet epitaxy allows us to use a lattice-matched system. Using a strain-free material system allows us to grow many closely stacked QD layers without degraded material quality. We investigated the stacking process of QDs on the (311)A substrate using GaAs and AlGaAs. We first characterized these materials structurally and optically. Atomic force microscopy (AFM) showed higher dot densities for samples grown on (311) A substrates and showed consistent structures among varying layers of QDs. Photoluminescence measurements were used to investigate the relationships between QD layer number and/or barrier thickness and material properties, such as peak position. Then, preliminary solar cells were fabricated and their performance was analyzed. Next steps include further investigation of coupling between quantum dots and optimizing the solar cell device.

Fabrication and Characterization of IR Pixels for High Speed Detector Applications

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Mid-infrared detectors have applications for security and surveillance, greenhouse gas analyzers, and medical imaging. High speed infrared detectors can be used to improve dual comb spectroscopy systems and enable IR free-space communications in atmospheric transmission windows. The disadvantages of current photodetectors such as p-n junction photodiodes and photoconductive cells include junction capacitance (p-n junction) and the need for invasive ohmic contacts. Here, we investigate a high-speed IR detector based on a resonant microwave circuit. A split ring resonator (SRR) is coupled to a microstrip and loaded with an IR pixel[1,2]. IR pixels are fabricated using photolithography, etching, and peel-off[3] before transfer into the device[2]. Measurements of minority carrier lifetime using the µ-TRMRR technique reveal sub-nanosecond lifetimes, potentially surpassing speed limits of conventional mid-IR photodetectors. Therefore, our pixel-loaded microwave resonator device is promising for applications requiring high bandwidth infrared detectors. Lastly, we develop a transmission line model to describe the circuit's RF frequency and time response.

References: [1], R. Liu, et al., Opt. Express, 24(23), 26044-26054, 2016. [2], S. Dev, et al., Nature Comm., 10, 1625, 2019. [3], M. Zamiri, et al., Appl. Phys. Lett., 108, 091110, 2016.

Silicon-on-Insulator Holey Photonic Crystal Waveguides for Mid-IR Gas Sensing

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Powerful on-chip gas sensing is desired for many environmental and healthcare applications. For instance, industrial agents like phosgene or arsine are toxic at < 5 ppm. It is possible to identify chemicals with high sensitivity in real time using infrared (IR) spectroscopy. There is high interest in mid-IR sensing (2-20 µm), which is fundamentally more sensitive than near-IR sensing for most chemicals. Development of on-chip mid-IR sensing has been catalyzed by recent advances in laser technology, but ideal waveguides are yet to be developed. Silicon-on-insulator-based waveguides are especially desired for their mature fabrication process. Photonic crystals enhance light-matter interaction when periodic hole defects are introduced. Thus, silicon-on-insulator holey photonic crystal waveguides (SOI HCPWs) have emerged as strong candidates for mid-IR sensing [1]

In this project, we designed SOI HCPWs for 3.43 µm light, simulating designs over a range of defect hole radii, waveguide widths, and device thicknesses. We calculated bandwidth, stopgap, and electric field intensities using the plane wave expansion method to evaluate waveguide testability and sensitivity. We determined an optimal defect-crystal radius ratio of 0.7 and waveguide width of W1 (1.732 µm), and chose a device thickness of 500 nm based on our results. Finally, we fabricated the waveguide. Future testing will revolve around characterizing the waveguide's light propagation and absorption sensitivity to ethanol.

Reference: [1] Zou, Y., Chakravarty, S., Wray, P., & Chen, R. T. (2015). Mid-infrared holey and slotted photonic crystal waveguides in silicon-on-sapphire for chemical warfare simulant detection. Sensors and Actuators B: Chemical, 221, 1094-1103.