REU 2016—Project Description

Research Topic #1: Silicon Nanowire Integrated ISFET Microchip for pH Sensing
Faculty Mentor: Uche Wejinya (PI), Ph.D., Associate Professor of Mechanical Engineering
Graduate Student Mentor: Yomi Omolewu

Problem Statement: The rapid progress in nanotechnology today has drawn more research attention in various fields, especially in biology, chemistry and medicine. Conventional pH sensors need a relatively large amount of target solution in order to realize effective pH measurement at least in milliliter scale. However, there are limitations when nano scale samples are involved in pH testing. Therefore, Silicon Nanowires (SiNWs) integrated Ion Sensitive Field Effect Transistor (ISFET) towards pH measurement for nanoliter/sub-microliter solution is proposed.
Objectives and Research Plan: The objective is to fabricate and test an Ion Sensitive Field Effect Transistor (ISFET). The research plan consists of three major tasks: MEMS techniques to fabricate ISFET, packaging and testing of ISFET as a pH sensor, and SiNWs alignment between electrodes using external forces such as Dielectrophoresis (DEP).
Training Plan: Weeks 1-4: AutoCAD and microfabrication; Weeks 5-7: testing of ISFET; Weeks 8-9: SiNWs alignment using DEP and corresponding electrical characterization.
Research Facilities: Micro and Nano Systems Engineering Laboratory and High Density Electronics Center.

Research Topic #2: AFM Based Investigation of Imaging and Tailoring of Graphene
Faculty Mentor: Uche Wejinya, (PI), Ph.D., Associate Professor of Mechanical Engineering
Graduate Student Mentors: Yomi Omolewu

Problem Statement: The numerous electrical and mechanical properties for which graphene possesses has paved the way into a new era of research and exploration since Nobel Prize in Physics was awarded to the pioneering graphene researchers Andre Geim and Konstantin Noveselov in 2010. In the midst of heavy research in synthesis and transport techniques, there is an enormous demand for the research in tailoring techniques for the future mass industrial usage of graphene within electronic devices. Therefore, a technique based on Atomic Force Microscopy (AFM) to reveal lattice structure and tailor graphene into a desired shape will be the central focus.
Objectives and Research Plan: The objective is to image and tailor graphene using AFM. The research plan consists of three major tasks: graphene sample preparation, AFM based imaging on graphene lattice structure, and AFM based surface nanomachining to tailor graphene into desired shapes with various combinations of parameters, such as force, speed, and electrical bias.
Training Plan: Weeks 1-2: AFM training; Weeks 3-4: imaging of graphene and offline filtering process; Weeks 5-6: surface nanomachining on graphene with focus on force and speed; Weeks 7-8: surface nanomachining on graphene with electrical bias.
Research Facilities: Micro and Nano Systems Engineering Laboratory

Research Topic #3: Numerical Simulations of Multi-Phase Fluid Flow in Microfluidic Channels
Faculty Mentor: Paul Millett (PhD), Assistant Professor of Mechanical Engineering
Graduate Student Mentor: Joseph Carmack

Problem Statement: Controlling and manipulating the flow of small volumes of fluids is the basis of an emerging technological field of research known as Microfluidics. Within this field, the study of multi-phase fluid flows (consisting of two or more immiscible liquids such as oil and water) within small channels is attracting significant attention. Such flows may consist of dense packings of bubbles, droplets, or foams that are compartmentalized and can potentially be utilized for a variety of applications such as artificial cells and micro-chemical reactors. A firm understanding of how dense droplets flow through small channels, and more importantly how we may be able to predictably sort, arrange, and order such droplets remains to be established.
Objectives and Research Plan: In this project, the objective will be for the REU student to conduct computer simulations of the flow of dense fluid droplets through microchannels with varying geometries including constrictions, channel forks and channel junctions. The research will utilize a Lattice Boltzmann model that has been implemented into a parallel c++ code. The REU student will gain experience running highly parallel simulations on the Arkansas High Performance Computing Center, as well as analyzing output data.
Training Plan: Weeks 1-2: Familiarization with the Unix HPC environment; Weeks 3-4: Submitting and Visualizing simulations, and developing the parametric study; Weeks 5-8: Analyzing simulation results, writing report, making poster.
Research Facilities: Millett Research Lab and the High-Performance Computing Center.

Research Topic #4: Nano-channel Based Two-Phase Separation
Faculty Mentor: Adam Huang, Ph.D., Associate Professor of Mechanical Engineering
Graduate Student Mentor: John Bishop Lee

Problem Statement: To date there have not been any nano-satellites, or smaller, with the mobility to change its orbit, perform coordinate formation flight, or proximity maneuvers. Although the reason for this is from multiple fronts (scientific, technological, safety, budgetary, and inter-agency politics), the key criteria tends to be safety and asset risk assessment related. Questions regarding mobility relates to the propulsive technology available, hence the propellant safety (explosion), toxicity (ground crew exposure), corrosive effects (damage to other satellites and launch vehicle in case of leak), orbital performance (orbital collisions), and clean-up (space debris) are the leading inhibitors. The goal of the mentor's current propulsion research is to demonstrate a non-toxic, non-flammable, and non-pressurized propellant micro-propulsion technology for nano-satellites using nano-channel based phase separation of liquid propellants.
Objectives and Research Plan: Training Plan: Weeks 1-2: Review of fluid mechanics, leading into nano-fluidics; Week 3-4: Introduction of relevant micro/nano-fabrication techniques (photolithography and nanolithography), Week 5-6: nano-channel fabrication, Week 7-8: test sample measurements. Training equipment includes basic micro/nano fabrication techniques and atomic force microscopy.
Research Facilities: Engineered Micro/Nano-Systems Laboratory (ENRC-3915) and UA High Density Electronics (HiDEC) Facility.

Research Topic #5: Understanding biological design architectures across scale boundaries
Faculty Mentor: Ajay P. Malshe, Ph.D., Distinguished Professor of Mechanical Engineering
Graduate Student Mentor: Salil Bapat

Problem Statement: Nature has unique architectures from honeycomb structure -to- dislocations at atomic lattice. These design architectures are critical for stability of their existence across length scale boundaries. These architectures are key mathematical design constructs fundamental in their nature.
Objectives and Research Plan: We will identify a bio-inspired test structure like honeycomb. The objective will be to study design construct. Study will include material and processes those correlate to mathematical construct of biological structure of interest. Energetics, mechanical and dynamics will be studies in the discovery process.
Training Plan: Weeks 1-2: Identification bio structure; Weeks 3-4: studying processes and materials; Weeks 5-6: On understanding mathematical framework; Weeks 7-8: on optimization of energetics of structure and real engineering application; Weeks 9-10: writing research report and presentation of results.
Research Facilities: Institute of Nanoscale Materials Science and Engineering, UA

Research Topic #6: 3D Printing of Micro/Nano-Patterned Surfaces for Tribological Applications
Faculty Mentor: Min Zou, Ph.D., Professor of Mechanical Engineering
Graduate Student Mentor: Yang Zhao and Raissa Araujo Borges

Problem Statement: It is estimated that a third to a half of the world's energy production is used to combat friction and wear ($500B/year in US alone). Reducing friction and wear in mechanical systems remains a significant challenge and will directly impact many applications, such as manufacturing, aerospace and defense, agriculture, and gas and oil industries. Our research effort focuses on nanoscale surface engineering to improve tribological performance and associated wetting properties of engineered surfaces.
Objectives and Research Plan: Low friction coatings, such as self-assembled monolayers and polymers, have been applied to surfaces to reduce friction, but they are easily worn due to weak mechanical properties and poor adhesion to substrates. The objective of this project is to develop novel 3D-printed mechanical surfaces inspired by nature and novel nanomaterials, which will provide superior low friction and surface durability for a broad range of mechanical systems for applications in both traditional and high-tech industries.
Training Plan: The REU student will develop 3D processes to fabricate the novel surfaces and study the friction and wear properties of the surfaces using Tribometer, characterize surface wear and wetting properties through surface profilometry and contact angle goniometry, respectively. Weeks 1-2: training on 3D printing; Weeks 3-4: developing 3D printing processes for patterning multi-materials; Weeks 5-6: fabricating samples and performing tribological testing; Weeks 7-8: surface wear characterization; Weeks 9-10: writing research report and presentation of results.
Research Facilities: Nanomechanics and Tribology Laboratory.

Research Topic #7: Microfluidic Systems Fabricated by 3D Printing
Faculty Mentor: Steve Tung, PhD, Professor of Mechanical Engineering
Graduate Student Mentor: Bo Ma

Problem Statement: Microfluidic systems have shown great promises in a large number of biological and biomedical applications such as genetic analysis, protein quantification, and pathogen detection. When compared to the conventional laboratory techniques, microfluidic systems have the distinct advantages of speed, portability, and cost. A majority of the current microfluidic systems utilize PDMS (polydimethylsiloxane) as the primary structural material. PDMS is a flexible polymer that can be molded into different microstructures using precision microfabrication tools. It is biocompatible and various biochemical protocols have been developed to enhance its properties. However, PDMS device fabrication is extremely time consuming and the process can be very costly. My laboratory is exploring the application of 3D printing to manufacture microfluidic devices directly from computer design files. Fundamentally, 3D printing is a precision material deposition technology that builds three-dimensional structures from polymers. Until recently, 3D printing has been confined to hobby-level projects since the availability of printable materials and their spatial resolution are somewhat limited. The research focus of my laboratory is to utilize the commercial desktop 3D printers to create high-precision three-dimensional microstructures for microfluidic systems.

Objectives and Research Plan: Students involved in this project will be trained on various high-precision manufacturing techniques including 3D printing. They will apply their training to the development of new microfluidic systems and conduct their work in a well-equipped laboratory. The objectives of the research include (1) evaluating the mechanical and biological properties of existing 3D printing materials, (2) developing the control parameters for printing microfluidic systems, and (3) evaluating the performance of 3D printed microfluidic systems and comparing their performance to that of the existing PDMS designs.

Training Plan: Weeks 1-2: 3D printing training; Weeks 3-4: 3D device fabrication; Weeks 5-6: 3D device testing; Weeks 7-8: 3D device integration and optimization; Weeks 9-10: research report writing and presentation.
Research Facilities: Micro and Nano Systems Laboratory.

Research Topic #8: Studying biodegradable, graphene oxide-turned carbon nanotubes
Faculty Mentor: Z. Ryan Tian, Ph.D., Associate Professor of Chemistry and Biochemistry
Graduate Student Mentor: Hulusi Turgut

Problem Statement: Carbon nanotube (CNT), regardless how much of effort has been put on the basic science and application potentials, the CNT's notorious cytotoxicity, carcinogenicity, poor biodegradability has been the major roadblocks on the way to mass-produce consumer-products out the CNTs of nearly all known forms. On the other hand, graphene (GA) derived materials such as graphene oxides (GOs) were recently found to be biocompatible and even biodegradable. Hence, we proposed that if the GAs or GOs could be wrapped into a carbon-nanotube, this new form of, say, GO-CNT may show the electronic and chemical properties close to that of the ordinary CNT, and at the same time show a biocompatibility and biodegradability similar to an ordinary biomaterial. Since 2015, our lab has been making progresses in synthesizing the GO-wrapped CNT, which resulted in some highly promising and publishable preliminary data. On this basis, a wide cope of physical (including mechanical) properties and chemical properties of this new CNT must be investigated asap.
Objectives and Research Plan: The REU student will be expected to make the GO-based CNT. Then, the REU student will use all known tools, both on campus and elsewhere in USA or oversea, to test the new CNT's physical and chemical/biological properties within the 10-week period in the summer-2016. The data out of this REU-research will be expected to be highly publishable, and even patentable or soon translational toward commercialization.

Training Plan:
Weeks 1-2: On GO-CNT synthesis;

Weeks 3-4: Structural characterizations (i.e. SEM, XRD, TEM, etc.)

Weeks 5-6: Nanoindentation, Young's modulus, heat conductivity, etc. through a close collaboration with Prof. Wejinya's lab.

Weeks 7-9: Testing GO-CNT's uses in harvesting and storing energy, nanoelectronics, biodegrabaility in Prof. Carbonero's lab in the Food Science Department, and Prof. Wei Shi's lab in in Chemistry/Biochemistry Department through continuous collaborations;

Weeks 10: Writing research report, and presenting the new data.

Research Facilities: The GO-CNT synthesis will be in Tian's lab and the Institute Nanoscale Materials Science and Engineering, UA

Research Topic #9: Micro Batteries for Wireless Sensor and Medical Applications
Faculty Mentor: Jie Xiao, Ph.D., Associate Professor of Chemistry and Biochemistry
Graduate Student Mentor: TBD

Problem Statement: Batteries employing lithium chemistry have been intensively investigated because of their high energy attributes which may be deployed for vehicle electrification and large-scale energy storage applications. Another important direction of battery research for micro-electronics, however, is relatively less discussed in the field but growing fast in recent years. This paper reviews chemistry and electrochemistry in different microbatteries along with their cell designs to meet the goals of their various applications. The state-of-the-art knowledge and recent progress of microbatteries for emerging micro-electronic devices may shed light on the future development of microbatteries towards high energy density and flexible design.
Objectives and Research Plan: This project will collaborate closely with industry to develop custom designed microbatteries to meet the energy and power goals of various applications such as micro transmitter and medical appliances. Both materials chemistry/electrochemistry along with interface modification and cell design will be investigated to deliver the final prototype batteries.
Training Plan: Weeks 1-2: Electrode fabrication process; Weeks 3-4: Cell design and quality control; Weeks 5-6: battery testing and diagnosis; Weeks 7-8: prototype micro batteries; Weeks 9-10: writing research report and presentation of results.
Research Facilities: Nanostructures and Manufacturing Lab and UA High Density Electronics (HiDEC).