Research Experiences for Undergraduates in Nanomaterials, Nanomechanics, and Leadership Training in Engineering

2017—Projects Description

Research Topic #1: Developing Palladium-Graphene-based hydrogen gas sensor
Faculty Mentor: Uche Wejinya, Ph.D., Associate Professor of Mechanical Engineering
Graduate Student Mentor: Yomi Omolewu

Problem Statement: The need for an alternative source of energy due the exhaustible nature of current source of energy and the need to reduce pollution are driving research in using hydrogen as an energy carrier in both mobile and stationary applications. Hydrogen sensors are integral part of this new research area because of the safety issues related with using hydrogen as an energy carrier. Incorporating nanomaterials with carbon based materials as graphene is been explored to improve the "4s" of sensors - sensitivity, selectivity, speed (response and recovery time), and stability. Investigation into the optimum nanoparticle size for improved sensor performance will provide insights to nanoparticle size considerations for hydrogen sensing applications. An improvement the design and functionality of hydrogen gas sensors will pave the way for a cleaner and more abundant source of energy, which will pave the way for a new hydrogen-driven economy.

Objectives and Research Plan: The electrical response of the palladium-graphene sensor will be investigated with the goal of improving sensor performance. Palladium nanoparticle on graphene does affect the electrical property of graphene, and how different nanoparticle sizes affect the performance of the sensor will be investigated. Graphene will be synthesized using the Hummers method, and palladium nanoparticles of different sizes will be deposited on graphene. The electrical response of the palladium-graphene device will be investigated and how this impact on the performance of the sensor will be investigated.

Training Plan: Weeks 1-2: Graphene synthesis and characterization; Weeks 3-4: palladium nanoparticles synthesis and characterization; Weeks 5-6: palladium/graphene sensor assembly; Weeks 7-8: electrical characterization of palladium/graphene sensor; Weeks 9-10: writing research report and presentation of results.

Research Facilities: Micro and Nano Systems Engineering Lab, Nanostructures and Manufacturing Lab, and UA High Density Electronics (HiDEC) Facility.

Research Topic #2: 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 #3: Platinum-Graphene Synthesis for Gas Sensing Application
Faculty Mentor: Uche Wejinya, Ph.D., Associate Professor of Mechanical Engineering
Graduate Student Mentor: Yomi Omolewu

Problem Statement: The need for an alternative source of energy due the exhaustible nature of current source of energy and the need to reduce pollution are driving research in using hydrogen as an energy carrier in both mobile and stationary applications. Hydrogen sensors are integral part of this new research area because of the safety issues related with using hydrogen as an energy carrier. Incorporating nanomaterials with carbon based materials as graphene is been explored to improve the "4s" of sensors - sensitivity, selectivity, speed (response and recovery time), and stability. Investigation into the optimum nanoparticle size for improved sensor performance will provide insights to nanoparticle size considerations for hydrogen sensing applications. An improvement the design and functionality of hydrogen gas sensors will pave the way for a cleaner and more abundant source of energy, which will pave the way for a new hydrogen-driven economy.

Objectives and Research Plan: The electrical response of the platinum-graphene sensor will be investigated with the goal of improving sensor performance. Platinum nanoparticle on graphene does affect the electrical property of graphene, and how different nanoparticle sizes affect the performance of the sensor will be investigated. Graphene will be synthesized using the Hummers method, and platinum nanoparticles of different sizes will be deposited on graphene. The electrical response of the platinum-graphene device will be investigated and how this impact on the performance of the sensor will be investigated.

Training Plan: Weeks 1-2: Graphene synthesis and characterization; Weeks 3-4: Platinum nanoparticles synthesis and characterization; Weeks 5-6: platinum/graphene sensor assembly; Weeks 7-8: electrical characterization of Platinum/graphene sensor; Weeks 9-10: writing research report and presentation of results.

Research Facilities: Micro and Nano Systems Engineering Lab, Nanostructures and Manufacturing Lab, and UA High Density Electronics (HiDEC) Facility.

Research Topic #4: Mechanical Behavior of Novel High-Strength Nanoscale Structures
Faculty Mentor: Min Zou, Ph.D., Professor of Mechanical Engineering
Graduate Student Mentor: Mahyar Afshar Mohajer / Drew Fleming

Problem Statement: Nanostructures can be used to alter the properties of solid surfaces. However, these structures deform very easily under contact stresses encountered in typical applications, which severely limits their durability. A novel nanoscale core-shell structure was recently discovered to have unusual high strength and deformation resistance; however, the nanoscale mechanisms that contribute to this unusual mechanical behavior are not currently known. The goal of this research is to gain a fundamental understanding of the mechanical behavior of the novel high-strength nanoscale structures, in order to design nano-textured surfaces using these structures for optimized mechanical performance. This research will provide valuable information to guide the rational design of nano-textured surfaces employing nanoscale core-shell structures for micro/nano-electro-mechanical systems and provide potential solutions for this multi-billion dollar industry to solve plaguing tribological issues. The novel nanoscale core-shell structure concept can also be applied to other applications, including magnetic recording, nanoimprinting, surface wetting, and biomedical applications, where mechanical integrity of the nanostructures is of paramount importance.

Objectives and Research Plan: The REU student will participate in research activities supporting the above research goal. The objective of this REU project is to develop processes to fabricate the core-shell structures and surfaces, study the mechanical, friction and wear properties of the surfaces using a TriboIndenter, and characterize the surface deformation and wear through surface atomic force microscopy (AFM) and scanning electron microscopy (SEM).

Training Plan: The REU will be trained on the basic research skills, such as literature search, experimental design, data analysis, and paper writing. The student will also learn several experimental techniques that are related to this project, including nanofabrication, surface characterization, and mechanical and tribological testing. Weeks 1: train on nanofabrication; Weeks 2-3: fabricate core-shell nanostructure; Weeks 4-7: Perform nanoindentation and tribological testing; Weeks 7-9: AFM and SEM training and characterization; Weeks 9-10: writing research report and presentation of results.

Research Facilities: Nanomechanics and Tribology Laboratory (NMTL).

Research Topic #5: Numerical Simulations of Particle Suspensions in Multi-Phase Fluids
Faculty Mentor: Paul Millett (PhD), Assistant Professor of Mechanical Engineering
Graduate Student Mentor: Joseph Carmack (PhD student)

Problem Statement: Multi-phase liquids such as oil-in-water (O/W) or water-in-oil (W/O) emulsions are commonly utilized in many scientific and industrial applications including materials processing, food sciences, skin-care products, thin-film coatings, and the extraction of fossil-fuels. Over time, the droplets in emulsions will coarsen due to droplet-droplet coalescence and other droplet coarsening mechanisms. In many instances, it is desirable to maintain droplet sizes within the sub-micrometer regime. Emulsion stabilization can be achieved by molecules or nanoparticles that absorb onto the fluid-fluid interfaces and prevent droplet coalescence and coarsening. However, we do not fully understand how solid nanoparticles behave on fluid-fluid interfaces and their stabilizing effect.

Objectives and Research Plan: In this project, the objective will be for the REU student to conduct computer simulations of multi-phase fluids that contain solid nanoparticles. The simulations will track the fluid-fluid phase separation process as well as the concurrent attachment of nanoparticles onto the fluid-fluid interfaces. Results will be collected that focus on the morphology evolution and the formation of particle-armored droplets that resist droplet-droplet coalescence. The research will utilize a fluid dynamics model that has been implemented in 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 #6: Micro/Nano-fluidics for Small Satellite Micro Propulsion System.
Faculty Mentor: Adam Huang, Ph.D., Associate Professor of Mechanical Engineering
Graduate Student Mentor: John Lee

Problem Statement: Nano/pico satellites have limited orientation capability partly due to the current state of microthruster devices. Development of a self-contained micro propulsion system would enable dynamic orbital maneuvering of pico- and nano-class satellites. Fluid vaporization via nanochannels to vacuum has not been found in literature and the limitations are unknown, but it could provide a novel method of propulsion for small satellites.

Objectives and Research Plan: Experiments have been designed and setups made to measure solution properties including density, evaporation rate, vaporization pressure, and flow rates through nano-channels. The REU student, starting with existing nanochannel chips, perform systematic and calibrated measurements. Student is expected to learn nanofabrication techniques specific to this research to develop and fabricate his or her own nano-channel feed device for characterization by the end of the REU.

Training Plan: Weeks 1: Familiarization with current research, background research; Weeks 1-5: HiDEC training, perform lab experiments on premade nanochannel chips; Weeks 5: Design own nano-channel chip; Weeks 6-8: Fabricate own nano-channel chip and tests; Weeks 9-10: writing research report, presentation of results, and help prepare conference/journal paper.

Research Facilities: Engineered Micro/Nano Systems Laboratory (EMNSL) and UA High Density Electronics (HiDEC).

Research Topic #7: Mechanical Properties of Nanocomposites
Faculty Mentor: Z. Arun Nair, Ph.D., Assistant Professor of Mechanical Engineering
Graduate Student Mentor: Raghuram Reddy S.

Problem Statement: With the availability of several one dimensional (1D) and two dimensional (2D) materials, and the ability to control the layer thickness and placement of these 1D and 2D materials on metal surfaces, there is a tremendous opportunity to explore these materials for application towards metal nanocomposites embedded with 1D and 2D materials. Recent studies conducted by the principal investigator (PI) and others on metal-graphene nanocomposites have shown that Ni-Cu graphene systems show high strength during nanoindentation, however fracture properties of these metal nanocomposites are largely unexplored. The orientation and spacing of 1D and 2D material systems in metal nanocomposites can play a critical role in their fracture properties. Here, we propose a set of computational studies to find, how to improve the fracture toughness of metal composites embedded with 1D and 2D materials.

Objectives and Research Plan: The objective of this study is to predict the fracture initiation, propagation, and fracture toughness of metal nanocomposites using atomistic models. The proposed study aims to accomplish the following: (a) Develop models of metal nanocomposites embedded with 1D and 2D materials, (b) study the fracture properties of the nanocomposite material system. The model developed and the results will help with design guidelines for metal nanocomposites embedded with 1D and 2D materials.

Training Plan: Weeks 1-2: Training on how to use supercomputer and simulation tools; Weeks 3-4: computational model setup and testing; Weeks 5-8: computational model validation and mechanical testing; Weeks 9-10: writing research report and presentation of results.

Research Facilities: Multiscale Materials Modeling Lab, Arkansas High Performance Computing Center.

Research Topic #8: Distantly Switchable Drug-Delivery on Nanofiber-Graphene Composites
Faculty Mentor: Z. Ryan Tian, Ph.D., Associate Professor of Chemistry and Biochemistry
Graduate Student Mentor: Parker Cole

Problem Statement: The nationwide cancer-fighting Moonshot Initiative has been inspiring researchers and manufacturers to team-up on tackling longstanding problems in diagnoses and therapeutics of cancers of all types. Among these problems, it's long-overdue to develop a versatile, low-cost, and patient-friendly drug delivery system that can deliver a wide range of drugs on demand, without the need of sacrificing the patient's life-quality. This is because for doing so, there exist some major technical challenges in design, selection, modification, surface-treatment, fabrication and integration of new biocompatible/biodegradable materials into such a low-cost system. This requires an integrated research effort across a wide range of topics, from materials synthesis and surface functionalization to drug-loading and programmable releasing in quantitative- and time-controllable manners. This type of smart drug-delivery system has been seldom reported in literature in any form.

Objectives and Research Plan: Based on our up-to-date preliminary data, we will use the biocompatible/biodegradable graphene oxide (GO) in composite of the biocompatible TiO2-nanofibers, all from Tian's lab, to develop the "Distantly Switchable Drug-Delivery" system. In particular, we will fabricate a drug-carrier with a porous wall on which an external stimuli-switchable "open-closure" mechanism can be realized. The stimuli include both heat- and pH-changes. Expectably, a distant signal such as heat and even a wireless signal will be integrated into the system that will allow the patients to switch the drug-delivery on demand whenever and/or wherever in need. This is an ongoing project initiated by a chemistry PhD student who needs some help from somebody with a solid chemical engineering or materials engineering training. Such a work will be highly publishable and patentable, and will most likely be done within a timeframe of 10 weeks or less. This training will stimulate the REU student(s) to explore future opportunities in STEM-related R&D fields, via pursuing a PhD degree to, hopefully, follow up this initial work.

Training Plan:
Weeks 1-2: The GO synthesis and characterization;
Weeks 3-4: TiO2-nanofiber based drug-carrier fabrication;
Weeks 5-6: Fabrication of the smart drug-delivery system;
Weeks 7-8: Drug-loading and programmable releasing'
Weeks 9-10: Summarizing the findings in a report, and an oral presentation.

Research Facilities: Tian's labs in Chemistry, NANO and UA High Density Electronics (HiDEC).

Research Topic #9: Developing Ultrathin Superior Surface Nano-coatings as Artificial Solid Electrolyte Interphases for High-performance Rechargeable Lithium-ion Batteries Using Atomic Layer Deposition
Faculty Mentor: Xiangbo (Henry) Meng, Ph.D., Assistant Professor of Mechanical Engineering
Graduate Student Mentor: TBD

Problem Statement: Rechargeable batteries are very promising in tackling energy challenges facing our modern society, by harnessing renewable clean energies and supplying electricity energy for portable electronics, transportation, smart grids, and autonomous devices. Currently, lithium-ion batteries (LIBs) are dominant in portable electronics, but not sufficient for transportation due to their limitation in energy density, safety, cost, and durability. One general issue in various LIBs is the formation solid electrolyte interphases (SEIs), due to the direct contact between the LIB electrodes with the liquid organic electrolytes. The formation of SEIs consumes liquid electrolytes and lithium, and ultimately increases the impedance of the LIB cells. This generally reduces the capacity of LIB cells, adversely shortens the cells' cyclability, and poses safety issues. In this context, researchers intensively have been searching for various surface coatings (acting as artificial SEIs) to protect electrodes from direct contact with liquid electrolytes. Traditionally, sol-gel methods have been developed for various surface coatings of LIBs, but the resultant coatings are very thick, ranging from several tens of nanometers to microns. In the past few years, atomic layer deposition (ALD) has been reported being a new research thrust for ultrathin surface coatings in the range from subnanometers to a few of nanometers, showing dramatic improvement in LIB capacity, stability, and safety with great cost reduction. To date, ALD has mainly reported metal oxides as surface coatings of LIBs, such as Al_2O_3, TiO_2, ZrO_2, and so on. These ALD coatings commonly have low conductivities ionically and electronically.

Objectives and Research Plan: In this project, we will develop new surface coatings with superior ionic conductivity. Our strategy is to develop lithium-containing ternary compounds with tunable ionic conductivities. The methodology is to combine two binary ALD processes. One of the two ALD process will be for lithium oxide, and another is for various metal oxides. By tuning the cycle ratio of the two individual ALD processes, we will be able to smartly adjust the content of lithium in the resultant ternary lithium-containing oxides in order for optimal lithium-ion conductivity. With the resultant ternary compounds, we expect LIBs will be able to harvest improved capacity, stability, and safety. At the same time, we will also demonstrate this ALD strategy will be cost-effective and the resultant coatings will be less than 5 nanometers for the best LIB performance.

Training Plan: Weeks 1-2: Synthesis new surface coatings of ternary lithium-containing oxides; Weeks 3-4: Characterization of the resultant surface coatings on various substrates; Weeks 5-6: Coating the new surface coatings on LIB electrodes and conducting characterization; Weeks 7-8: Testing the ALD coated and uncoated LIB electrodes, and analyzing the effects of ALD surface coatings; Weeks 9-10: writing research report and presentation of results.

Research Facilities: Meng's Nano and Energy Lab, UA Nano-Bio Materials Characterization Facility (NBMCF), and UA High Density Electronics (HiDEC) Facility.