Science and Technology at the Nanoscale: MSE Research Experience for Undergraduates, 2019

Department Overview

Materials Science and Engineering is essential to the practice of engineering and technology as all facets of engineering depend critically on the materials utilized for specific applications, ranging from semiconductors for computer chips to polymers for new electronic devices. One important goal of this work involves the development of processes for altering the structure of materials and thereby controlling their properties. This field brings together developments in Physics, Chemistry and Biology in a unified discipline in order to apply them in development of modern materials of technological, engineering, and scientific significance. Materials scientists and engineers utilize a distinctive suite of characterization techniques such as advanced electron microscopes that probe materials structure down to the atomic level. Moreover, our faculty is extremely active with nanotechnology, energy-related materials and bio-materials.

REU Program Overview

The MSE department was granted VPUE and SoE funding to support undergraduate research during the summer of 2019 as part of the MSE Research Experience for Undergraduates (REU) Program: Science and Technology at the Nanoscale. REU participants will have an opportunity to work closely with an MSE faculty member in an area of interest to the student (e.g. nanotechnology, energy materials, bio-materials, mechanical behavior of materials, etc). REU students are paired with a Ph.D. student or post-doctoral scholar who will serve as a mentor on a daily basis. Weekly meetings of the REU students are held where, over the course of the summer, each student will have an opportunity to present their project and research results to his or her fellow REU participants. At the end of the program, students will present their work during a poster session at the 2019 MSE Summer Research Symposium.

Application Process

The application form is available online at [http://mse.stanford.edu/student-resources/research-experience-for-undergraduates](http://mse.stanford.edu/student-resources/research-experience-for-undergraduates)

Application submission is available online at [http://web.stanford.edu/~jdeanw/matscireu2019.fb](http://web.stanford.edu/~jdeanw/matscireu2019.fb)
Applications are due Friday, March 1, 2019 at 6pm. Please include a copy of your unofficial transcript.
The initial application process involves a short questionnaire in which students will rank their research project preferences. Please note that project titles are subject to change due to the dynamic nature of materials research. Students are strongly encouraged to familiarize themselves with a faculty member's research areas, as it is possible that students will be assigned to another project within the group. Multiple students may be assigned to each faculty member. Each student will have his or her own unique project.

After reviewing applications, individual faculty members may, depending on availability, meet with selected students before making a final decision. Final decisions will be communicated in April.

All Stanford undergraduates in good academic standing are eligible and encouraged to apply. Seniors graduating in June 2019 or earlier are not eligible.

Program duration

The program officially runs from Monday, June 24th - Friday, August 30th. Students may wish to be on campus the week before June 24th get a head-start on their project! Attendance on both the first day and last day are mandatory. On Monday, June 24th, REU students will have an orientation, lunch with faculty, and a mandatory lab safety training. On Friday, August 30th, students will present their summer's work to the broader Stanford community at the 2019 MSE Summer Research Symposium.

Financial Support

Students will receive a stipend of $7500. Room and board are NOT included.

Housing

Students are responsible for arranging their own housing for the summer. Housing on campus can be obtained by applying for summer housing through the University (https://rde.stanford.edu/studenthousing/assignments-contracts). In addition, plenty of off-campus housing is available in nearby Palo Alto, and summer sublets in graduate student residences are often available on campus. These can be found on Craigslist.org, SUpost.com, and similar websites.
Program requirements

The expected time commitment for the 10 week program is 40 hours/week. This will vary from week to week and from project to project. Typically, students will find themselves busier towards the end of the summer as they become fully independent researchers. Students are encouraged to fill free time during the beginning weeks with reading background materials and familiarizing themselves with the lab's research activities and equipment. A strong sense of initiative is a crucial ingredient to having a successful experience in the program.

Students will be expected to prepare for their summer project during the Spring quarter by attending research group meetings, reading background material related to their project, and completing any specialized safety and equipment training if possible or necessary before the start of the summer. During the summer, students will attend weekly group meetings with their respective research groups and faculty mentors and participate in enrichment activities with the other undergraduates, including weekly meetings where REU students will present on their projects. At the conclusion of the summer, each student will prepare a poster with results from his or her research project for a departmental symposium.

Stanford undergraduates in good academic standing are eligible to apply. Seniors graduating in June 2019 or earlier are not eligible. This grant may not be used to support honors research projects. Students participating in this program may not register for more than 5 units of coursework nor may they work for more than 10 hours per week in addition to their research appointment. Academic credit for participating in the summer program will not be awarded.

Contact Information

Department Coordinator: Jacob Wilson, Student Services Specialist
Materials Science & Engineering
Stanford University
496 Lomita Mall, Durand Building, Rm #113
Stanford, CA 94305-4034
Email: jdwilson@stanford.edu
Participating Faculty and Summer Research Project Descriptions

**Professor Eric Appel**

*Sustained Delivery of Biopharmaceuticals*

Protein therapeutics are a fast-growing class of pharmaceuticals exhibiting many advantages over traditional small-molecule drugs and which play an important role in almost every field of medicine, from oncology to endocrinology to infectious disease. Yet biopharmaceutical formulation is particularly challenging on account of the inherent instability of many proteins, their propensity to aggregate, and difficult administration of formulations at therapeutically ideal concentrations for extended periods of time. We seek to exploit rational design principles to engineer a novel class of injectable hydrogel materials for biopharmaceutical formulation that can address all of these issues. In particular, we are interested in understanding how we can control the diffusion to enable sustained release of different kinds of molecules over the course of months. Students will have the opportunity to learn polymer synthesis and characterization as well as protein structure and function characterization.

**Professor Bruce Clemens**

*Nanoparticles for photoelectrocatalysis*

The goal of this project is to develop novel nanoparticles to promote photoelectrocatalysis, where incoming solar energy is converted into storable energy such as hydrogen or methanol.

**Professor Will Chueh**

*Atomic Control & Characterization of Materials for Batteries, Fuel Cells & Electrolyzers*

Materials used in next-generation batteries, fuel cells and electrolyzers usually span 10+ orders of magnitude in length scale from meters to Angstroms, and have complex chemistry and nanostructures. As a result, fundamental understanding of electrochemical properties related to efficiency, lifetime and reliability is still lacking. In this project, you will create atomically-defined model systems that mimic real materials for energy storage and conversion technologies. These model systems simplify the chemistry and microstructure so that we can obtain a better understanding of the intrinsic properties of materials. Advanced characterization such as electron and X-ray microscopy and spectroscopy will be used to understand these processes in-situ during device operation. Empowered with fundamental insights, our ultimate goal is to rationally design electrochemical materials with improved efficiency, lifetime, and reliability.
Professor Yi Cui

"Nanomaterials design for energy applications"

This project explores the materials design to address the problems in the area of energy conversion and storage. Some applications examples include thermal textile, batteries and electrocatalysis. Students will have an opportunity to learn the skills of nanomaterials synthesis, structure characterization, energy device fabrication and testing.

Professor Reinhold Dauskardt

“Nano-Mechanical Behavior and Reliability in Energy Devices”

The intent of this project is to study the nano-mechanical properties and adhesion of advanced thin-film structures that have applications in a wide range of emerging technologies. The goal of the work is to develop a fundamental understanding of how the films’ mechanical properties are related to their nanostructure and processing conditions. In particular, we will be interested in how the films are affected by the presence of selected solution chemistries that may be associated with processing or operating conditions. The student will gain familiarity and experience with a number of experimental techniques, including thin-film sample preparation and adhesion testing, and the use of atomic force microscopy, X-ray photoelectron spectroscopy, and possibly scanning electron microscopy for analyzing fracture surface composition and morphology.

“Biomechanical function of human skin”

A quantitative in-vitro experimental biomechanics approach to examine the biomechanical properties of human skin which are vital for its function but poorly understood. Students will use a range of thin film characterization techniques to explore the outermost stratum corneum layer of skin and determine the effects of preconditioning treatments and cellular structure. We would also like to expand the research project to include multiple layers of skin. The project involves applying novel and new micromechanical and characterization techniques to study the structure and biomechanical function of human skin. Students will learn to separate, enzymatically treat and condition human skin, fabricate specimens, and conduct testing and analysis using methodologies developed in our research group. Analysis techniques such as scanning electron and optical microscopy will be employed, together with newly developed techniques involving wafer curvature and bulge testing of soft tissues.
Professor Jennifer Dionne  
“Mapping intracellular forces in the immune synapse with upconverting nanoparticles”
Immune cells undergo a range of mechanical feats to identify and target pathogen cells for death. While the mechanical forces are critical for immune cell performance, there is currently no suitable sensor for mapping the intracellular forces. We are working on developing biocompatible mechanical force sensors based on upconverting nanoparticles (UCNPs) with nanometer spatial resolution capable of imaging intracellular mechanical forces. A summer intern will be working on characterizing UCNPs force sensitivity by mimicking biological forces with an atomic force microscope (AFM) while recording the upconversion spectra. A summer student will also learn how to characterize UCNPs materials properties using transmission electron microscopy (TEM) and x-ray diffraction (XRD). Through careful materials studies and characterization, we will provide a new way to track immune cell interactions.

Professor Sarah Heilshorn  
“Design of biomaterials with nanoscale precision through protein engineering”
A unique approach to designing biomaterials involves mimicking the tools evolved by nature to create functional materials at the molecular level. The REU student will be involved in the synthesis, purification, and characterization of protein-based biomaterials using engineered bacterial hosts. These biomaterials will be evaluated for use as regenerative medicine scaffolds to induce the formation of new tissue.

Professor Guosong Hong  
“Deep brain stimulation with NIR light absorbing semiconducting polymers”
Neuron-type specific modulation of brain activity with light by optogenetics has opened up enormous opportunities for neuroscience studies. Expansion of the neural modulation toolbox from visible to near-infrared (NIR) wavelengths (750-1700 nm) offers deep brain stimulation capability in freely behaving animals without optical fiber, owing to the significantly reduced scattering of photons in the brain tissue at wavelengths up to 1700 nm. In this project, you will develop a deep brain stimulation technology based on various semiconducting polymers, which have tunable bandgaps and exhibit high photothermal conversion efficiency in the NIR window. Following synthesis, biocompatible surface functionalization and optimization of the semiconducting polymer materials, their neuron-stimulating performance will be tested in both in vitro neuron culture with simultaneous neuron activity measurement and in vivo experiments to modulate specific behaviors of freely behaving animals with NIR light. The ultimate goal of this project is to demonstrate a minimally invasive neural modulation technology based on free-space NIR light with remote control of deep-brain activity and behavior of live animals.
**Professor Aaron Lindenberg**  
*“Using light to manipulate two-dimensional materials and their functionality”*  
This project is broadly focused on visualizing the atomic-scale steps that underlie how two-dimensional materials and their heterostructures can be dynamically manipulated on ultrafast time-scales. A number of applications to next generation photonic devices follow from this work, including new possibilities for high bandwidth topological switches and nano-devices. Summer students will learn to use light spanning the range from x-rays to the far infrared to probe this functionality, and get first hand experience building these devices from scratch.

**Professor Paul McIntyre**  
*“Ge-Sn Nanowires for Mid-Infrared Silicon-Compatible Photonics”*  
In this project, we are growing Ge-Sn alloy nanowires that incorporate unusually high Sn concentrations needed to achieve a direct semiconductor band gap, required for efficient light emission and absorption. By preparing these crystals in the form of free-standing nanowires, they can be integrated onto silicon substrates without forming defects (dislocations) that would compromise their optoelectronic properties. A summer REU student working on this project will help develop improved methods for controlling the diameter and strain state of the nanowires, and will characterize their thermal stability with respect to germanium-tin phase separation. These topics are critically important to the development of efficient Ge-Sn light emitters and absorbers for applications including chemical sensing, thermal imaging and LIDAR.

**Professor Nicholas Melosh**  
*“Materials Science Approaches to Quantum Bits”*  
Quantum computing and sensing are exciting new areas of technology, yet require precise control of the placement and coupling to each quantum bit. We are exploring a materials-based approach to control the location and type of nitrogen- and silicon- vacancy defects in diamond, which can be used for quantum sensing and computing. This employs many fundamental materials concepts, where we explore the role of temperature, time, and growth conditions on the quality and quantity of defect sites.

**Professor Evan Reed**  
*“Computer modeling and machine learning for energy materials”*  
This project involves the development and use of machine learning and other computer algorithms to predict materials properties from the atomic structure. Materials focus will be two dimensional materials like MoS2, phase change materials for electronics applications, and electrolyte and other battery materials for energy storage applications.
Professor Alberto Salleo
"Art+Science research project with SSRL and Cantor"

The focus of the Fellow’s research can address a wide range of issues, including studies in technology and identification of materials. The Fellow can assist in authentication, validating authorship, age, state of preservation, and method of construction, and also could help determine provenance in collaboration with faculty, science students, conservators and other institutions. Other areas of research could include testing new materials for artists and conservators, or studying the aging and degradation of artist’s materials. New analytical equipment might be developed. Students will be supported by museum professionals, Stanford faculty and research scientists as they develop and lead their rigorous research project (“technical art history”), using scientific equipment at Cantor and at relevant laboratories on campus. Techniques and technologies might include: x-ray fluorescence; reflectance spectroscopy, microscopy; mass spectrometry; x-ray diffraction; laser; and hyper-spectral imaging, among others.

“Soft materials for mixed ionic and electronic transport”

This project will focus on the fabrication and characterization of thin film devices for the transduction of ionic fluxes into electrical currents. These devices find applications in bioelectronic and sensing of physiological signals. The materials involved are typically polymer blends. The student will learn how to make electrochemical thin film transistors and how to characterize their electrical properties. Both the ionic and electronic conductivity will be measured as a function of processing and morphology. The ultimate goal is the fabrication of a non-volatile transistor, which is a type of device that cannot be easily made using conventional electronic materials.

Professor Andrew Spakowitz
“Theoretical Exploration of the Microstructural Organization of Polymer Membranes for Water Purification”

Polymeric materials play a critical role in a broad range of applications, owing to their versatility, low cost, and ability to modify their properties through additives and processing. However, rational design of polymeric materials remains challenging due to the combinatoric possibilities of monomer chemistry and materials synthesis conditions, leading to the application of trial-and-error materials discovery strategies. Using computational modeling, this research project aims to reveal the molecular determinants of microstructural organization in a class of polymeric materials—random copolymer membranes—that exhibit heterogeneous order. Such materials play a critical role in water purification membranes, where the microstructural organization dictates the pathways for water, ion, and solute transport. This research program will establish design rules for polymer membranes with tailored
microstructural order, providing critical insight into the rational design of polymer membranes for water purification.

Professor Shan Wang

“Risk stratification of atherosclerotic plaques through DNA methylation profiling”

Coronary artery disease (CAD), which is a leading cause of death worldwide, is characterized by the formation of atherosclerotic plaques. Currently, there is no method to reliably predict a heart attack; most tests for CAD are aimed at detecting symptoms of atherosclerosis (e.g., diminished blood flow), but these tests fail to determine plaque stability and, therefore, the likelihood of imminent rupture. CT scanning for CAD diagnosis is becoming more common. With CT, physicians are able to measure the amount of calcification within the plaque, which has been linked to plaque stability. Unfortunately, CT scans are costly, expose patients to radiation, often require the use of contrast agents, and are time-consuming. Additionally, CT is not suitable for early assessment of plaques (e.g., prior to calcification). In this project we aim to develop a blood-based test for early assessment of atherosclerosis. Using the GMR biosensor previously developed in Professor Wang’s lab, we will be probing peripheral blood samples for DNA originating from the coronary arteries. By looking for specific epigenetic markers within the DNA, we will gain insight into the status of the plaques.