Spring 2014 IMR Facility Grants
Awarded by the OSU Institute for Materials Research (IMR)

Eleven new research projects were awarded by the IMR in June 2014, for a total investment of $22,000 in nascent materials research. The eleven projects support faculty researchers from eight different departments within the College of Engineering, College of Arts and Sciences, and College of Food, Agricultural and Environmental Sciences.

Laser-Material Interaction of Nano-patterned Ceramic Surfaces

Sheikh Akbar, Materials Science and Engineering; Co-Investigator: Enam Chowdhury, Physics

The proposed research is based on previous work in the PI's laboratory which has led to the development of a low-cost and high throughput process by which self-assembled nanostructures can be produced due to a morphological instability created by intermixing of rare earth oxides on yttria-stabilized zirconia (YSZ) single crystal surfaces leading to the formation of nanoislands or nanobars to relieve strain energy. The most remarkable feature of this type of self-assembly is that it does not require lithography or any other process to guide the nanostructure formation. Furthermore, the nanostructures tend to align along certain crystallographic directions on the substrate surface, a process dictated by the elastic modulus anisotropy of the substrate. The major focus of the proposed research is to improve the ordering of these nanostructures by surface engineering while further deepening our understanding of the mechanism by which this selfassembly phenomenon takes place. Additionally, exploratory research will be conducted on the coupling of femto-second laser on these surfaces to study novel effects such as metastable state formation, enhancement of ordering of nano-structures, field confinement, collective motion and plasmon coupling.

PDMS Honeycomb Templates to Probe the Force Footprint and Stiffness of Cells

Peter Anderson, Materials Science and Engineering; Co-Investigators: Jianjun Guan, Materials Science and Engineering; Heather Powell, Materials Science and Engineering; Gunjan Agarwal, Biomedical Engineering

The goal of this project is to produce a high-throughput system with which to study the forces generated by cells during stages of cell differentiation and growth. This will be achieved by synthesis of multi-well networks from the polymer PDMS (polydimethylsiloxane). Each well will accommodate an agarose or other gel containing biological cells. Through a combined experiment-simulation approach, the forces exerted on the gel and on the cells within it can be determined as a function of time, cell concentration, and external imposed deformation on the network. The effort will generate the ability to correlate cellular forces and stiffness with the differentiation and growth of cells. This important capability can advance the development of strong engineered skin and the ability to enhance the differentiation and growth of cardiomyocytes in engineered patches for heart cell regeneration.

Probing the Aging Effects of Nanomechanical Properties of Thin-Film LiFePO4 Li-Ion Batteries

Bharat Bhushan, Mechanical and Aerospace Engineering

Li-ion batteries offer great promise for future due to their superior gravimetric and volumetric energy density. One of the challenges is to improve the cycle life of Li-ion batteries which requires detailed understanding of the aging phenomenon. The aging mechanism of Li-ion batteries can have both chemical and mechanical origins. While the chemical degradation mechanisms have been studied extensively, mechanical degradation mechanisms have received little attention so far. In this proposed study, we will probe the changes in mechanical properties (i.e., elasticity of modulus and hardness) of a thin film $LiFePO_4$ cathode by comparing unaged and aged samples. Furthermore, we will study different cathode coatings (i.e., Al_2O_3) to understand their effects on suppressing the degradation in mechanical properties of $LiFePO_4$ cathode. To the best of our knowledge this will be the first time that nanomechanical characterization of $LiFePO_4$ active material will be performed. Based upon the preliminary result from this work, larger proposals on degradation mechanisms of Li-ion batteries are targeted for submission to external agencies such as Department of Energy (DOE) and National Science Foundation (NSF).

Selective Conversion of Methane to Methanol through Synthesizing Uniform Catalytic Sites

Nicholas Brunelli, Chemical and Biomolecular Engineering

Creating catalytic materials to selectively convert methane to methanol will enable a transformation to the methanol economy. The critical needs remain to synthesize a highly active and uniform catalytic site. Current synthetic methods produce a distribution of catalytic sites that are unable to create the desired catalytic site. We will develop novel synthetic techniques to achieve highly uniform and active catalytic sites for selectively converting methane to methanol.

Relationship of Rubber Particle Composition and Structure to Material Properties

Katrina Cornish, Horticulture and Crop Sciences and Food, Agricultural and Biological Engineering

The structure and composition of rubber particles produced by different plant species appears to be related to rubber material performance. Dynamic mechanical analysis of compositional subfractions of rubber particles indicate that the rubber particle core contains more than just rubber, and the outer membrane of the particle of different species appears to influence overall rubber properties beyond the effect of compositional differences. We will microscopically examine the surface features, and cross-sections of the rubber particles and relate visual architectural features to compositional and performance differences.

The First Solution-Phase Synthesis of Metal Carbide Materials

Joshua Goldberger, Chemistry and Biochemistry

The electronically conducting yet refractory transition metal carbide ceramics have attracted considerable interest in catalytic applications including efficient biomass conversion and fuel cell reactions. Unfortunately, the preparation of these carbides has been limited to extremely high temperatures ($T >> 250^{o}C$) due to the need to break the strong C-H bonds in all previously employed C^{4-} molecular precursors, like CH_4. This eliminates the possibility of preparing carbide materials in morphologies that employ surface-terminating ligands to stabilize the structure. Here, we seek to demonstrate for the first time, that crystalline transition metal carbides (specifically WC, VC, and NbC as model systems) can be prepared at mild temperatures ($T = 25\text{-}220^{o}C$) by the solution phase reaction of a novel C^{4-} precursor $C[B(OCH_3)_2]_4$ upon reaction with transition metal halides. If successful, this would open up a program on the solution-phase synthesis of carbide nanomaterials and dimensionally-reduced materials, their catalytic and electrocatalytic properties, and 3D-printing of these refractory ceramics.

Single Cell Sampling in Single Cell Culture Wells Using Microdroplets

Derek Hansford, Biomedical Engineering

Modification of the surface chemistry of a nanoporous membrane will allow us to encapsulate a femtoliter volume of aqueous phase (microdroplet) within an oil phase liquid. By combining this with our single cell culture wells, we will be able to sample the fluid surrounding individual cells in culture for study of their secretions in response to stimuli for drug discovery and metabolism studies. This grant will support the fabrication and testing of the modified SiCCWells for microdroplet formation.

Computationally Enhanced Electron Backscatter Diffraction Framework for Mesoscale Exploration

Stephen Niezgoda, Materials Science and Engineering

Cross-correlation electron backscatter diffraction (CC-EBSD) is a new technique for the in-situ measurement of elastic strain fields and geometrically necessary dislocation densities in the scanning electron microscope (SEM). While promising, several technical challenges must be overcome before it can realistically be applied to stress analysis in deformed polycrystals. The PI has proposed a computationally enhanced analysis technique for CC-EBSD data for polycrystalline materials to overcome several of these limitations. Work performed under this proposal will be aimed at collecting sufficient proof-of-concept results to seek external funding. Funds will be used to offset instrument use fees and to purchase metallographic supplies and consumables.

Biomaterials for the Efficient Production of Hydrogen Gas from Water: Towards Solar Fuels

Hannah Shafaat, Chemistry and Biochemistry

This project seeks to develop materials based on engineered protein scaffolds for highly efficient conversion between hydrogen gas, protons, and electrons. These systems can be used in hydrogen production or oxidation for bioderived and biocompatible devices. Characterization of these systems in solution and on surfaces will provide insight into the molecular principles governing morphology, surface attachment, and catalytic mechanism; ultimately, these materials can be coupled with light-harvesting moieties for solar fuel production.

Integrated Shear Force-Scanning Electrochemical Microscopy Nanoelectrodes for Imaging Soft Electrochemical Materials and Surfaces

Vishnu Sundaresan, Mechanical and Aerospace Engineering; Co-Investigator: Venkat Gopalan, Chemistry and Biochemistry

A major constraint for electrochemical imaging of biomolecule-immobilized electroactive surfaces is the ability to operate a probe proximal to the surface. A recent tool that has overcome this limitation is a scanning electrochemical microscope (SECM) equipped with shear force (SF) imaging, where simultaneous characterization of topography and correlated electrochemical activity is possible. Although SF-SECM has been used to study metallic and polymeric surfaces, current designs of quartz-based SECM nanoelectrodes cannot image biomolecules and cells owing to the relative hardness of quartz compared to soft materials. To address this shortcoming, Sundaresan's group is currently developing novel SECM nanoelectrodes that will enable the imaging of soft materials such as a single neuronal cell, immobilized transfer RNA (tRNA) molecules, etc. This IMR facility grant requests funds for the fabrication of these novel constructs of robust Si-SiO2-based SECM nanoelectrodes with integrated SF modules at Nanotech West, characterization at CEMAS and application in Sundaresan's lab using tRNA molecules synthesized by the Gopalan lab. The outcome of this award will lead to new knowledge on functional characterization of biomolecules using SF-SECM-FL imaging and leverage this advance to seek federal support (DoE, NIH and NSF) in Spring 2015.