Winter 2016
IMR Facility Grants Awards

THE OHIO STATE UNIVERSITY
INSTITUTE FOR MATERIALS RESEARCH

Nine new research projects were awarded by the IMR for a total investment of $18,000 in support of innovative materials research. These nine projects support sixteen researchers from nine different departments within the College of Engineering, College of Arts and Sciences, and College of Medicine.

Microstructural Analysis Near the Phase Boundary in Dissimilar Metal Welds for Nuclear and Fossil Power Generation Applications

Principal Investigator: Boian Alexandrov, Materials Science and Engineering; Co-Investigator: Michael Kuper, Materials Science and Engineering

Currently, steel dissimilar metal welds (DMWs) with nickel based filler metals are used in a variety of industrial applications, including fossil fired and nuclear power generation. In the case of advanced combined cycle fossil fired power plants, transitions must be made from the stainless steel used in the high temperature gas generators to the creep strength enhanced ferritic steels (Grade 91 and 92) used in the lower temperature steam generators that recover heat from primary exhaust gasses to boost plant efficiency. As plants continually work to maximize their efficiency, usage of DMWs continues to grow. Unfortunately, the DMWs used to manufacture heat recovery steam generators (HRSGs) are prone to unpredictable and premature failure that occurs in a narrow band near the phase boundary between Grade 91 Steel and the nickel based filler metal of the DMW. As such, the importance of identifying the failure mechanism is elevating beyond the critical level. The focus of the proposed research is therefore to use more advanced characterization techniques, including electron backscatter diffraction, to determine the solidification structure of the regions around the phase boundary and the evolution of that structure throughout the lifetime of the weld. The results will then be used to discuss the possible effects of the microstructural changes on the properties near the site of failure, which will provide useful insight into the failure mechanism for these unpredictable failures.

Weld Solidification Behavior of CoCrFeNi-based High-Entropy Alloys

Principal Investigator: Carolin Fink, Materials Science and Engineering; Co-Investigator: João Pedro Oliveira, Materials Science and Engineering

This research seeks an initial characterization of the weld solidification behavior of CoCrFeNi-based high-entropy alloys (HEA). The acquired experimental observations will be greatly valuable as a precursor to a more comprehensive weldability assessment of this exciting new alloy class, which will be pursued by the PIs in near-future grant proposals to external funding agencies. Addressing welding in the early stages of HEA development is critical in order to identify any potential weldability issues and to enhance the engineering application of HEA as materials for structural applications. The proposed work involves detailed characterization of the non-equilibrium weld metal microstructure using X-ray diffraction analysis (XRD) and scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS) and electron backscattered diffraction (EBSD) capability, and direct measurement of the solidification temperature range of the HEA systems through thermocouple plunging experiments in conjunction with single sensor differential thermal analysis (SS-DTA™).

High Resolution EBL Nanopatterned GaN Epitaxy

Principal Investigator: Tyler Grassman, Materials Science and Engineering and Electrical and Computer Engineering; Co-Investigator: Siddharth Rajan, Electrical and Computer Engineering; Aimee Bross Price, Institute for Materials Research

We propose the development of a single-step patterned oxide epitaxial process, using an electron beam lithography (EBL) cured hydrogen silsesquioxane (HSQ) mask and GaN molecular beam epitaxy (MBE) re-growth. HSQ is a clean resin made from only H, Si, and O, which when cured by an electron beam, formed a pure silicon oxide solid. Direct dielectric patterning, without the use of a pattern transfer step, would reduce process complexity and enable ultra-high resolution structure fabrication. EBL patterning makes use of an infrared laser to measure the local height of the sample and adjust focus, to ensure proper pattern fidelity and quality. However, this simple technique is not possible on infrared transparent materials such as GaN and related substrates such as SiC and sapphire. An alternative approach must be developed that allows for accurate height measurement/focus and does not negatively affect the HSQ chemically. The work proposed here will focus initially on developing that height measurement technique. The main objective of this work, however, is to determine the selectivity of the GaN plasma-assisted MBE (PA-MBE) regrowth to HSQ. Either extreme, complete overgrowth or complete selectivity could have beneficial applications in GaN short channel devices or buried photonics.

Flexible Photocatalytic Films of Polypyrrole/ZnO-Nanorods for Wearable Solar Cells

Principal Investigator: Liang Guo, Electrical & Computer Engineering and Neuroscience

The goal of this proposal is to develop a highly flexible photocatalytic film that is functional under visible light. Thin solid films of wide bandgap semiconductors such as ZnO (bandgap 3.37 eV) and TiO2 (bandgap 3.20 eV, anatase) have been widely used in dye-sensitized solar cells, self-cleaning glasses, and gas sensors due to their capabilities of generating photon-induced reactive oxygen species under visible light1-3. Flexible and wearable films of such materials are highly desired for many emerging fields, such as stretchable electronics and wearable devices. However, flexibility of such semiconductor photocatalysts is limited due to the rigid nature of solid films. We propose a new structure for PPy/ZnO composite, in which the lower half of the ZnO nanorods is embedded within a flexible PPy layer. The PPy layer absorbs visible light and converts low-energy photons into electrons, which further hop into the conduction band of ZnO leaving highly oxidative holes in the valence band. Such an indirect excitation mechanism is widely used in dye-sensitized solar cells and proven effective for PPy/ZnO particles as well. Completion of this grant proposal will offer a soft and robust photocatalytic film for flexible solar cells, which could facilitate numerous applications varying from wearable electronics to the energy industry.

Preparation and Characterization of Magnetic Tips for Spin Polarized Scanning Tunneling Microscopy

Principal Investigator: Jay Gupta, Physics; Co-Investigator: Roland Kawakami, Physics

Scanning tunneling microscopy has allowed the analysis of systems with atomic scale resolution, but can be improved by allowing the detection of electron spin state orientation. This can be achieved by coating a non- magnetic tip with a thin film of magnetic material, preferably an antiferromagnet, with a zero net magnetization but with a well-defined magnetization at the tip apex. It has been demonstrated that chromium is an excellent candidate for such coatings due to its antiferromagnetic behavior and thickness tunable spin orientation. Here, we will utilize the NSL facility to develop and optimize production of Cr coated PtIr tips for spin polarized scanning tunneling microscopy. The FIB will be used to remove oxides from the surface of the tips, then tips will be characterized using the SEM to ensure tip apex radii of < 100 nm. Using the Lab 18 sputtering system to deposit Cr films, we will produce coatings with a targeted thickness of N50 monolayers to allow both in-plane and out-of-plane magnetic sensitivity. These tips will be used in a new spin polarized STM system for atomic scale studies of magnetism in bulk and 2D semiconductors, as well as Skyrmion materials such as FeGe.

Development of a New Generation of Double-Sided Heat-Flux Gauges

Principal Investigator: Randall Mathison, Mechanical and Aerospace Engineering; Co-Investigator: Richard Celestina, Mechanical and Aerospace Engineering

Double-sided heat-flux gauges have been a critical part of gas turbine heat transfer research since they were first introduced in 1986. Following several iterations and improvements made by researchers at the Calspan Corporation and The Ohio State University, the double-sided heat-flux gauge evolved into what it is today – a unique measurement tool specific to The OSU Gas Turbine Laboratory that captures temperature data by utilizing a material's resistance response to a change in temperature. The current research proposal plans to modernize and build upon the current capabilities of the double-sided heat-flux gauge by introducing a new gauge material, gauge and lead geometry, and manufacturing method. The goal of this research proposal is to create a new generation of heat-flux gauges by collaborating with the experts at Nanotech West Laboratories and utilizing the capabilities of that facility. In addition, the improved manufacturing capabilities of Nanotech West enables the development of high-density heat-flux gauges that pack a number of sensors in a tight geometric region. The current research is laid out in two stages: process development and testing, in which a process flow is created and deposition techniques are tested; and manufacturing, in which high quality final products are produced and inspected. Work has already begun in the development stage and has rendered promising results. Each stage is estimated to take between two and three weeks. Given the number of gauges capable of being produced during one manufacturing iteration, this research promises to be a highly cost effective and time saving method for producing these unique data collection tools and offers a plethora of opportunities for further developments and modifications in the future.

Synthesis of Novel Benzobisoxazole-Linked Covalent Organic Frameworks for the Catalytic Conversion of Carbon Dioxide to Value Added Chemicals

Principal Investigator: Psaras McGrier, Chemistry and Biochemistry

The conversion of anthropogenic carbon dioxide (CO_2) into a value-added chemical or fuel could potentially supplement the carbon cycle and reduce environmental concerns. As a consequence, harnessing and transforming CO_2 into a beneficial carbon feedstock is highly desirable. Current transformation methods involve the direct hydrogenation of carbon dioxide to methanol and formates, but these pathways are thermodynamically unfavorable for large-scale conversions. An alternative route is the reduction of CO_2 by hydrosilylation to silyl formates. This method provides a thermodynamically favored pathway that is driven by the activation of the Si-H bond of the hydrosilane and formation of the strong Si-O bond to create silyl formates, which can be converted to formamides, formates, or alcohols. This proposal focuses on constructing novel benzobisoxazole (BBO)-linked covalent organic frameworks (COFs) containing Cu-doped bidentate phosphine ligands to catalyze the conversion of carbon dioxide to feedstock chemicals. The specific aims of this project are to (1) explore the ability of BBO-COFs containing bidentate phosphine ligands to effectively bind Cu to form chemically stable structures, and (2) investigate the ability of the Cu-doped BBO-COFs to uptake and convert significant amounts of CO_2 to formic acid.

Electron Microscopy for Cell Junction Remodeling due to Fluid Stress

Principal Investigator: Shaurya Prakash, Mechanical and Aerospace Engineering; Co-Investigator: Jonathan Song, Mechanical and Aerospace Engineering

Endothelial cells (ECs) comprising the inner lining of blood vessels are continually exposed to mechanical forces due to fluid flow. Inspired by the challenges in studying the cell mechanics that are critical for regulating vascular morphogenesis and function, we developed 3-D angiogenesis-on-a-chip (AoC) technology that allows for controlled application of fluid mechanical stimuli to pre-formed vessel analogues in vitro. Using our AoC approach, we discovered that the orientation of interstitial fluid flow (IF) relative to the endothelium is crucial for triggering polarized vessel sprouting. In this proposal, we will take the next step for discovery by integrating our AoC technology with high-resolution electron microscopy techniques to elucidate the ultrastructure of endothelial sprouting in response to impinging versus extravasating IF. Critically, we expect to discover how IF imparts structural changes at intercellular junctions between adjacent ECs. If successful, the proposed research will: (i) greatly advance the field of mechanobiology by providing direct and quantitative measurements of endothelial sprouting phenotypes attributed directly to mechanical stimulation associated with IF, (ii) significantly enhance our understanding of how ECs serve as a biomechanical interface for vessel guidance, and (iii) provide essential preliminary data for larger proposals.

Characterization of Amphiphilic Polymer Films for Controlling Cell Attachment

Principal Investigator: Katelyn Swindle-Reilly, Biomedical Engineering and Chemical and Biomolecular Engineering

Amphiphilic polymers have been developed in our laboratory to control cell attachment. These polymers are being developed for prevention of scar formation in corneal wound healing and for prevention of posterior capsule opacification after cataract surgery. This project aims to determine the material properties that are influencing the response of ocular cells on these polymers. The mechanical properties of the polymers will be determined using atomic force microscopy or nanoindentation, and the surface properties of the polymers will be determined using optical profilometry and contact angle measurements.