GRADUATE RESEARCH OPPORTUNITIES
Innovation for TOMORROW
Research Overview

BIOMATERIALS AND BIOTECHNOLOGY

Biomaterials: Magnetic materials are being used to create novel therapies and medical diagnostics, such as detection of diseased tissue, cancer treatment, and triggered drug release. Also, tissue engineering principles are used to create improved models to better treat cancer.

Nanobiotechnology: Research activities consist of preparation of nanomaterials using biological scaffolds, development of improved drug systems, and environmental effects of nanomaterials.

Cell Engineering: Advanced bioprocessing techniques are being used to grow large-scale quantities of cancer stem cells, in order to assist translational medicine and cancer therapies. Also, metabolic engineering is allowing large-scale production of biofuels and pharmaceuticals.

COMPUTATIONAL

Molecular Simulations and Electronic Structure Calculations: This research involves applying molecular-level simulations and electronic structure calculations to predict the thermodynamics and properties of molecules, bio-molecules, fuel cells, carbon nanotubes, and new catalysts.

ELECTRONIC MATERIALS AND DEVICES

Electronic Materials/Thin Films: Research addresses the fundamental understanding of atomic scale processes occurring during the synthesis of electronic materials. Special emphasis is given towards deducing the chemical reactions, thermodynamic driving forces and physical phenomena that govern the material’s physical, optical and electronic properties.

Synthesis of Electronic Materials: This research effort focuses on the controlled synthesis and assembly of nanomaterials and nanostructures. The objective of this effort is the discovery of novel phenomena exhibited by materials in the nanoscale.

Thermoelectric Materials/Sensors: The main goal is to develop nanostructured thermoelectric materials to improve the heat-to-electricity conversion efficiency for waste heat recovery.

ENERGY/ENVIRONMENTAL

Petroleum and CO₂ Sequestration: This research focuses on new ways to sequester CO₂ emissions and the evaluation of various aspects of CO₂ enhanced oil production. Research efforts also include the development of numerical modeling and 3-D visualization tools.

Alternative Energy: Heterogeneous catalysis is used to produce and purify hydrogen from fossil fuels. Electrocatalysis is studied for fuel cell electrodes, photovoltaics, batteries, and supercapacitors. Major objectives include improving the activity and stability of the catalysts and finding less expensive metals. Biogas is produced from wastewater treatment sludge.

Functionalized Membranes for Separation and Reaction: Research involves addition of adsorption and catalytic properties to porous membranes and thin films through the grafting of functional polymers. Research includes high capacity membrane adsorbers for monoclonal antibodies, pharmaceuticals, heavy metals, and catalytic membranes for alkylation and esterification.

Industrial Gas Capture: Ionic liquids and related compounds are being investigated as green solvents for capturing industrial CO₂ emissions and many other applications. They can also be used for natural gas sweetening, by removing H₂S and NH₃ from the natural gas.

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Dr. Heath Turner, hturner@eng.ua.edu
Dr. Bao’s group focuses on designing novel multifunctional nanoparticles for biomedical applications, such as targeted drug delivery, bio-imaging, and cell tracking. They are also exploring engineered biological templates for the synthesis of nanomaterials.

Magnetic nanoparticles have significantly advanced cancer treatments through targeted drug delivery and localized therapy. Magnetic nanoparticles further make simultaneous therapy and diagnosis possible as magnetic resonant imaging (MRI) contrast agents.

One of the unique aspects of Bao’s research is the creation of a suite of iron oxide nanoparticles of different shapes as MRI contrast agents and for other biotechnology related applications. These shapes include spheres, cubes, nanowires, plates, flowers, etc.

To further enhance the imaging capability of these nanoparticles, Dr. Bao’s group designs magnetic-fluorescent integrated nanoparticles using iron oxide as the magnetic component and metallic nanoclusters as the fluorescent component. This multifunctional nanostructure also has the potential to serve as dual contrast agents for MRI and CT scans.

Much of Dr. Bao’s works are directly related to the engineering of material interfaces. Her group developed a facile method to attach various molecules onto nanoparticle surfaces for water solubility and desirable functionality, such as tumor targeting.
Dr. Bara’s research group is focused on development of advanced polymer materials, processes for clean energy production, green chemical manufacture, 3-D printing, big data, and scientific apps for iPhones and iPads.

Dr. Bara is a recognized leader in the design and synthesis of advanced polymers and composites based on ionic liquids. These materials provide unprecedented opportunities to create stable nanostructured materials with highly tunable chemical and physical properties for applications including CO₂ capture, water purification, superabsorbents and 3-D printing.

Capturing CO₂ from power plant flue gas and other industrial sources is one of the greatest engineering challenges of the 21st Century. Dr. Bara’s group focuses on the design and study of new high-performance solvents to efficiently capture CO₂ and/or SO₂ at various process conditions. Several solvents developed in Dr. Bara’s lab are in the process of being commercialized and have been tested in large pilot plant demonstration projects.

Dr. Bara’s group is also studying “green” solvents from glycerol and other renewable resources and developing straightforward methodologies for their mass production.

Dr. Bara has also developed several widely used apps for iPhones/iPads including Chemical Engineering AppSuite, ODEesseus and Engineering Unit Converter.
The Brazel Laboratory is developing nanomaterials for medical and biopharmaceutical applications. Recent foci in the lab include: (1) development of targeted and triggered magnetic micelles that combine hyperthermia with release of anti-cancer drugs, and (2) developing a robust toxicology assay to evaluate polymer films for single-use cell culture/fermentation.

The combination of the nanoparticles with polymeric micelles with crystalline cores allows a magnetic field to trigger release of chemotherapy agents. The Brazel Lab work includes synthesis of iron oxide nanoparticles, block copolymers, such as poly(caprolactone-b-ethylene glycol) (below) and hydrogels as well as characterization of the properties and functionality of these materials.

The lab collaborates with researchers in chemistry, biology and the medical sciences to further develop these materials for human health applications. Nanotechnology offers great promise for biomedical applications, as this size range (which also includes most micelles) allows interaction and targeting to specific cells and tissue in the body (for example, using peptides like RGD shown above). Electron microscopy (TEM image of magnetic micelles below, left), and high frequency magnetic heating (envisioned using an infrared camera, bottom right) are used to validate the system. We seek to understand the fundamental chemistry and physics of the materials and phenomena to guide the optimization of drug delivery devices, while considering the interaction of new materials with both the human body (therapeutic effect) and the environment (potential toxicology).

Recent Publications


Christopher Brazel

Associate Professor
Ph.D. Chemical Engineering
Purdue University, 1997

Biopolymers, Drug Delivery, Nanotherapeutics, Magnetic Hyperthermia, Single-use Bioprocessing Films

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Dr. Gupta’s group focuses on controlled synthesis and assembly of nanomaterials and nanostructures, with emphasis on the exploration and manipulation of materials’ physical and chemical properties and their potential applications.

Spintronics, also known as magneto-electronics, is an emerging technology which exploits the intrinsic spin of electrons and its associated magnetic moment, in addition to its fundamental electronic charge, in solid-state devices. Spintronics exploits electron spin, creating a new class of devices that can potentially be scaled down to nano-dimensions and can also provide additional functionality. The group is interested in the growth and characterization of novel magnetic thin films by a variety of deposition techniques, including chemical vapor deposition, pulsed laser deposition, etc. for the fabrication of devices, such as magnetic tunnel junctions and spin-based semiconductors, and their application for storage, memory, and logic-based devices.

Nanomaterials are of great interest for a wide range of applications, including catalysis, data storage, biotechnology/biomedicine, etc. In particular, the synthesis of monodisperse uniform-sized nanocrystals using solution-based methods is of key importance for these applications because of their strong dimension-dependent physical and chemical properties. Dr. Gupta’s research group is interested in the synthesis of functional oxides and chalcogenides in the form of nanoparticles and other nanostructures with controlled shape, size, structure, etc.

In addition to traditional methods for the synthesis of inorganic nanomaterials, novel approaches are being developed that exploit advances in biotechnology. The bio-inspired approach to materials synthesis has successfully utilized cells, viruses, and biomolecules, such as nucleic acids, proteins, etc., to produce inorganic nanomaterials with controlled crystal morphology, phase structure, and size, under mild conditions.
Dr. Huang’s group focuses on developing electrochemical technologies to fabricate new materials and structures for applications in microelectronics, renewable energy, and biomedical devices.

Interconnect is a network of metal wires in integrated circuits, which enables the communication between semiconductor devices. The state-of-the-art Cu interconnects (below left figure) is currently facing a big challenge, where Cu resistivity increases exponentially as the dimension of wires decreases. We are exploring the chemistry and process to enable the fabrication of interconnects with other metals, which do not suffer the same resistivity increase. In addition, we are investigating the electrodeposition of novel interconnects for quantum computers.

Chalcogenide compounds of transition metals find a variety of applications, including phase change (see above on the right) memory, piezoelectric switches, thin film solar cells as well as electro- and photocatalysts. Our group is developing electrodeposited chalcogenide nanomaterials including thin films, nanowires and nanoparticles for those applications. Our research focuses on the understanding of nucleation and growth of such nanomaterials with a long term goal to make electrodeposition the viable process to fabricate memory devices.

Other focuses of our research include the development of a 3-D printing technology for metals based on electrodeposition. In addition, we are developing a biomedical device using electrochemically created nanomaterials. Anodization methods to create nanopore templates with controlled pore location and size are investigated. Furthermore, nanowires with compositional modulation at nanometer scale are fabricated (see on the right).
Dr. Jeon’s group focuses on developing advanced multifunctional materials and assembly techniques for energy-related research. Our current effort is to fabricate nanostructured functional materials for energy storage.

Energy has become one of the most important issues in the world due to the continual increase in its consumption and the depletion of fossil fuels. In response to these challenges, great effort has been focused on the development of more efficient energy-related applications, such as energy storage and energy conversion.

Lithium-ion batteries are among the most widely used electrochemical energy storage systems in portable electronics; due to their high energy density. However, the price of current inorganic electrodes is still relatively high for automotive and other applications. Conjugated polymers can also store charge based on their redox properties, and are more cost-effective and versatile. However, their low stability generally leads to a short cycle life, which hampers its widespread applications. We are focusing on developing novel, organic-based, electrode materials possessing improved electrochemical properties such as high energy density and power density. Our main approach is to utilize a variety of synthesizing and processing techniques for electroactive nanomaterials, in order to obtain enhanced electrochemical properties. Another one of our research focuses is on advanced responsive multifunctional materials, whose physicochemical properties can be tuned in response to various stimuli. We are expecting these materials to be viable in a wide range of applications including electrochromic devices, sensors, and solar cells.

Recent Publications


The Kim laboratory is working on bioprocessing expansion of cancer stem cells to better assist translational medicine. Cancer stem cells (CSCs) are considered the stem cell-like pluripotent cancer cells that cause relapse in patients even after the most rigorous treatment.

Pharmaceutical companies, however, typically use several decades-old cancer cell lines during their drug development because, among many reasons, (1) CSCs are hard to acquire and (2) are limited in number. It is becoming increasingly recognized, however, drug development must be based on CSCs to develop better drugs that target the "real culprit" in tumors. Therefore, the work at the Kim Laboratory aims to bridge the oncologists with the engineers by developing large scale quantities of CSCs using engineering principles and systems biology tools (e.g. proteomics) for the mass production of CSCs from primary patient tissues and cell culture. By doing so, they hope to assist in the drug development by providing a more relevant and closer-to-clinic resource of cancer cells.
As electronic, magnetic and photonic devices become more sophisticated, there is an ever-pressing need to fully understand the physics and chemistry of solid interfaces. Technologies such as spin valves, field effect transistors, and nano-laminate optical coatings are all comprised of ultra-thin films in the nanometer thickness regime.

At this dimension, bulk thermodynamic properties governing film stability, diffusion, and reactions as well as bulk electron transport mechanisms that determine device performance no longer apply. Hence, there is a need to develop novel preparation procedures for thin film structures with abrupt interfaces for incorporation in new devices and in test devices which probe fundamental physical phenomena like electron scattering at interfaces in giant magneto resistance (GMR) and tunneling magneto resistance (TMR) recording heads.

Atomic Layer Chemical Vapor Deposition is a promising technique for the fabrication of nanometer scale thin films for alternate high k gate dielectrics in field effect transistors, dielectrics for magnetic tunnel junctions, and metal thin films for spin valves, optical coatings, or diffusion barriers for interconnects. The process involves a separation of the reaction sequence into two self-limiting steps dependent on the availability of functional groups present on the surface. This allows the formation of an atomic layer one step at a time, resulting in excellent film uniformity, conformality and thickness control.

Attenuated total reflectance Fourier transform infra-red spectroscopy (ATR-FTIR) reaction cell is used to observe initial reaction pathways in real time. An IR light beam is focused on the backside of a heated Si, Ge or ZnSe ATR crystal and is bounced though as it is totally reflected at the gas surface interfaces. Some of the light extends as an evanescent wave into the reaction zone on the topside of the ATR crystal and is used to identify key chemical groups involved in the reaction sequence.
Dr. Peng’s group focuses on understanding the surface/interfacial phenomena during the assembly of materials from molecular building blocks (Molecular Legos). With these fundamental knowledge, the group is interested in developing assembly strategies of ultrathin new materials to address challenges facing the sustainable energy utilization.

Energy is critical to the sustainable development of the human society. Most of the challenges in the human society can be addressed if we can harvest a large amount of energy in a sustainable way. New materials play the critical role in developing sustainable methods of energy utilization. Surface/interfacial properties of the materials often determine the performance of the materials in the energy related applications ranging from solar energy conversion, electrochemical energy conversion and energy storage, 2D microelectronics, flexible electronics and biomaterials.

Our interest is to develop new methods to assemble materials with control of the composition and structures down to the atomic level. We are interested in understanding the nucleation and growth mechanisms of ALD (Atomic Layer Deposition) and its derivatives by in-situ/ex-situ analytic methods to grow materials with the controlled physiochemical properties. With the thorough understandings of the devices’ physics and substrate chemistry, we are also interested in employing novel molecular assembly strategies in tuning the surface/interfacial chemistry and micro-structures of materials, and establishing the structure-property relationship of materials.

The projects will be explored in Dr. Peng’s research group.

1) Surface reaction mechanism of ALD;
2) Perovskite solar cell;
3) Catalysts for energy harvesting.
The Rao Laboratory is developing engineering tools to unravel the mechanisms associated with the role of microenvironment in cancer progression, therapeutic response and resistance.

The oncogenic progression of cancer from the primary to the metastatic setting is the critical event that defines stage IV disease, no longer considered curable. Despite some success in developing a suite of therapies, a key challenge that continues to hamper cancer treatment is the frequent development of drug resistance, particularly in the metastatic setting, resulting in disease relapse and often mortality. Most existing experimental models to investigate tumor cell responses to therapeutic treatments and examine mechanisms of drug resistance utilize two dimensional (2D) substrates (e.g., plastic, glass) that largely fail to recapitulate the complex in vivo environment.

Our research group is designing three dimensional (3D) biomaterial scaffolds (e.g., hydrogel scaffolds, and porous scaffolds) as tools to mimic features of tissues that could serve as platforms for elucidating physiologically relevant cellular behaviors, drug screening and discovery, as well as mechanisms of drug resistance in the context of cancer therapeutics in vitro and in vivo. In addition, we are developing biomaterial tools that could be employed for sensing and modulation of drug resistance. We are also interested in applying systems biology approaches to understand the underlying mechanisms of therapeutic resistance in physiologically relevant 3D microenvironments. This knowledge could be subsequently utilized to devise strategies that can reprogram the microenvironment to halt disease progression. Given that drug resistance is a major issue noted across multiple types of cancers, this work would have far reaching implications in drug discovery and development, thereby transforming current treatment strategies.
Dr. Ritchie’s laboratory focuses on the addition of active properties to passive materials. This work has resulted in adsorptive membranes for antibody purification, highly charged membranes for protein separation and concentration, and membrane catalysts. Commercial production of functionalized membranes and scale-up are also of interest.

The group’s interest in adsorptive membranes has been focused on antibody purification. The work is continuing and evolving to include other biomolecules and more complex adsorption sites. Adsorptive membranes are fully synthetic and high capacity, and are capable of achieving similar selectivity to affinity resins.

We also have a strong interest in commercial production techniques and applications for functionalized membranes. Currently, work is focused on high volume systems containing proteins and other biomolecules. The goal is to concentrate proteins similar to conventional microfiltration and ultrafiltration processes, but at much higher flux through a combination of separation mechanisms beyond size exclusion.

The group’s interest in acid catalysis has been on low temperature reactions where the competing solid-phase catalyst is strong acid ion exchange resin. Our current interest is adapting membranes for long-term operation in industrial systems. We are targeting applications with reactive distillation is currently employed.
The Summers lab is working to metabolically engineer bacteria and yeast cells to produce chemicals, fuels, and pharmaceuticals. Specifically, the group focuses on engineering enzymes, gene networks, and genetic regulatory elements in microbial cells.

Caffeine is a natural product produced by many plants and consumed by humans worldwide. However, high caffeine consumption has also led to large amounts of caffeinated waste from coffee and tea processing plants. This can have detrimental environmental effects, as caffeine is toxic to most bacteria and insects. The Summers lab has a growing collection of bacteria capable of growing on caffeine as sole carbon and nitrogen source. From these bacteria, new genes and enzymes are being discovered that can be used in a variety of biotechnological applications. Through a combination of systems biology, protein engineering, and molecular biology, the lab is engineering yeast to simultaneously decaffeinate coffee waste and ferment the sugars in the waste to ethanol. Additionally, bacterial strains to produce high-value chemicals from caffeine are being created. The group is also working to determine the structures of caffeine-degrading enzymes in bacteria using X-ray crystallography.

Other projects in the Summers lab include metabolic engineering of probiotic bacteria for \textit{in situ} delivery of amino acids, characterization of genetic regulatory elements in probiotic bacteria, design of modular plasmids for metabolic engineering of \textit{E. coli}, \textit{Saccharomyces cerevisiae}, and other microbial strains, and construction of novel riboswitches that recognize small molecules.

As society moves away from use of petroleum resources for production of fuels and chemicals, their replacements must come from natural, renewable resources. To meet this need, the Summers lab seeks to engineer bacteria and yeast cells to produce bulk and fine chemicals from biomass. In addition to these chemicals, the group is looking at production of pharmaceuticals and nutraceuticals in metabolically engineered microbial cells.
Dr. Turner’s group uses computer simulations to investigate adsorption and reactions on surfaces and at interfaces. Their work helps guide the synthesis of new nanomaterials, identify new catalysts for environmental applications, and design unique solvent molecules for CO₂ separation technologies.

The Turner group uses molecular simulations and quantum mechanical calculations to screen new materials for a variety of clean energy technologies. In the field of catalysis, we are using kinetic Monte Carlo simulations to help identify an environmentally-benign route for synthesizing propylene oxide using gold-based nanoparticles. Also, we are using molecular simulation tools to screen solvents for producing thermoelectric materials (such as Bi₂Te₃), which can be used to capture waste heat from a variety of sources. In terms of CO₂ capture, we are developing efficient simulation tools for quickly screening and identifying effective solvents and polymers for CO₂ capture applications. In all projects, we work closely with experimental collaborators, in order to regularly benchmark our models and develop reliable predictions.

Recent Publications


Dr. Van Zee’s group applies the principles of chemical engineering to electrochemical systems. These applications include corrosion, batteries, fuel cells, and industrial production of chlorine and caustic. 

Electrochemical engineering provides a path toward the development of cost-effective sustainable alternative energy systems. These topics include electroplating of alloys for circuit boards and corrosion resistant light weight materials as well as energy conversion devices such as fuel cells and batteries. Recent projects on concentrated solar power and improving fuel cells are described below to provide an idea of our approach.

Concentrated solar power systems may use inexpensive molten chloride salts at temperatures approaching 900 °C. In these systems, the combustion of fossil fuels in the boiler of a Rankine cycle is replaced by a heat exchanger with a solar-heated high temperature molten salt. To design economical systems, it is necessary to understand corrosion behavior of lower-cost tubes and structures used in the heat exchangers and storage tanks. In these aggressive environments with non-specialty materials, corrosion appears to proceed via selective oxidation of Cr at the grain boundary. Models of these phenomena, which include mass transfer, kinetics, thermodynamics, and potential theory, are being developed to describe the corrosion mechanisms. These models of the chromium concentration ($C_{Cr}$) are time-dependent two-dimensional and require meshing at the micron level (see below). The goal is corrosion mitigation strategies.

In the search to lower the capital cost for low temperature fuel cells, off-the-shelf polymeric materials may be used for the balance of plant. These materials meet the stress-strain requirements in vehicles, but they may contain leachable species which contaminate and decrease both performance and fuel cell life. By using in-situ and ex-situ data, the Van Zee group has developed models that predict the voltage loss as a function of the chemistry of the functional groups in the leachates.
The Materials Engineering And Nanosensor [MEAN] Laboratory studies and develops advanced materials, fundamental biomedical & environmental sensor platforms, and drug delivery scaffolds utilizing nanotechnology and biotechnology.

The MEAN Laboratory lies at the interface of materials science/engineering, bionanotechnology, and surface (interfacial) science. From studying fundamental material properties and applications of nanomaterials comes innovative advanced materials, nano/bio-sensors, and bio-compatible materials applicable to a number of fields and disciplines—including:

- Materials Chemistry
- Analytical Chemistry
- Polymer Chemistry
- Electrochemistry
- Portable and POC Devices
- Environmental Engineering
- Physics
- Biology
- Theranostics

Selected Recent Publications
