Materials Science & Engineering

The Institute of Materials Science & Engineering (IMSE) at Washington University in St. Louis offers a unique, interdisciplinary PhD in Materials Science & Engineering that crosses traditional departmental and school boundaries. The field of materials science and engineering focuses on the study, development and application of new materials with desirable properties, with the goal of enabling new products and superior performance regimes. Disciplines in the physical sciences (chemistry, physics, etc.) frequently play a central role in developing the fundamental knowledge that is needed to design materials for a variety of engineering applications (mechanical engineering, electrical engineering, chemical engineering, etc.). Building on training that spans from fundamental-to-applied sciences, materials scientists and engineers integrate this fundamental knowledge in order to develop new materials and match them with appropriate technological needs.

The IMSE is well positioned to address the needs of a student seeking a truly interdisciplinary experience. Established in 2013, the IMSE brings together a diverse group of faculty from departments in Arts & Sciences, the School of Engineering & Applied Science, and the School of Medicine. The IMSE integrates and expands the existing materials activities at Washington University by overseeing shared research and instrument facilities, creating partnerships with industry and national facilities, and setting up outreach activities.

Current focused areas of research and advanced graduate education within the IMSE include:

- **Biomedical, Bio-derived, and Bio-inspired Materials**
- **Materials for Energy Generation, Harvesting, and Storage**
- **Materials for Environmental Technologies & Sustainability**
- **Nanomaterials and Glasses**
- **Materials for Sensors and Imaging**
- **Thin Film & 2D Materials**

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**Website:** http://imse.wustl.edu

**Faculty**

**Director**

Katharine M. Flores  
Professor - Mechanical Engineering & Materials Science  
PhD, Stanford University  
Professor Flores' primary research interest is the mechanical behavior of structural materials, with particular emphasis on understanding structure-processing-property relationships in bulk metallic glasses and their composites.

**Professors**

Richard Axelbaum  
The Stifel & Quinette Jens Professor of Environmental Engineering Science  
PhD, University of California, Davis  
Rich Axelbaum studies combustion phenomena, ranging from oxy-coal combustion to flame synthesis of nanotubes. His studies of fossil fuel combustion focus on understanding the formation of pollutants, such as soot, and then using this understanding to develop novel approaches to eliminating them. Recently, his efforts have been focused on addressing global concerns over carbon dioxide emissions by developing approaches to carbon capture and storage (CCS).

Pratim Biswas  
Lucy & Stanley Lopata Professor & Department Chair - Energy, Environmental & Chemical Engineering  
PhD, California Institute of Technology  
Professor Biswas's research interests include aerosol science and engineering; nanoparticle technology; air quality engineering; environmentally benign energy production; combustion; materials processing for environmental technologies, environmentally benign processing, environmental nanotechnology, and the thermal sciences.

William Buhro  
George E. Pake Professor in Arts & Sciences and Department Chair - Chemistry  
PhD, University of California, Los Angeles  
Synthetic inorganic and materials chemistry; optical properties of semiconductor nanocrystals, including quantum wires, belts and platelets; metallic nanoparticles; magic-size nanoclusters; nanoparticle growth mechanisms; and charge and energy transport in nanowires.
Shantanu Chakrabartty (https://engineering.wustl.edu/Profiles/Pages/Shantanu-Chakrabartty.aspx)
Professor - Electrical & Systems Engineering
PhD, Johns Hopkins University
Shantanu Chakrabartty's research explores new frontiers in unconventional analog computing techniques using silicon and hybrid substrates. His objective is to approach fundamental limits of energy efficiency, sensing and resolution by exploiting computational and adaptation primitives inherent in the physics of devices, sensors and the underlying noise processes. Professor Chakrabartty is using these novel techniques to design self-powered computing devices, analog processors and instrumentation with applications in biomedical and structural engineering.

Sophia E. Hayes (http://www.chemistry.wustl.edu/people/primary-faculty/sophia-e-hayes)
Professor - Chemistry
PhD, University of California, Santa Barbara
Physical inorganic chemistry; materials chemistry; solid-state NMR; magnetic resonance; optically-pumped NMR (OPNMR); semiconductors; quantum wells; magneto-optical spectroscopy; quadrupolar NMR of thin films and tridecameric metal hydroxide clusters and thin films; carbon capture, utilization and storage (CCUS); CO2 geosequestration; CO2 capture; in situ NMR; metal carbonate formation.

Kenneth F. Kelton (http://www.physics.wustl.edu/people/kelton_kenneth-f)
Arthur Holly Compton Professor of Arts & Sciences - Physics
PhD, Harvard University

Vijay Ramani (https://engineering.wustl.edu/Profiles/Pages/Vijay-Ramani.aspx)
Roma B. & Raymond H. Witcoff Distinguished University Professor of Environment & Energy
PhD, University of Connecticut
Vijay Ramani's research interests lie at the confluence of electrochemical engineering, materials science and renewable and sustainable energy technologies. The National Science Foundation, Office of Naval Research and Department of Energy have funded his research, with mechanisms including an NSF CAREER award (2009) and an ONR Young Investigator Award (ONR-YIP; 2010).

Lan Yang (https://engineering.wustl.edu/Profiles/Pages/Lan-Yang.aspx)
Edwin H. & Florence G. Skinner Professor - Electrical & Systems Engineering
PhD, California Institute of Technology
Professor Yang's research interests are fabrication, characterization, and fundamental understanding of advanced nano/micro photonic devices with outstanding optical properties. Currently, her group focuses on the silicon-chip based ultra-high-quality micro-resonators made from spin-on glass. The spin-on glass is a kind of glass obtained by curing a special liquid using sol gel or wet chemical synthesis to form a layer of glass. The main advantage of the spin-on glass is the easy tailoring of the nano/micro structure of the glass by controlled variation in the precursor solutions. It enables them to fabricate various micro/nano photonic devices from advanced materials with desired properties.

Associate Professors

John Fortner (https://engineering.wustl.edu/Profiles/Pages/John-Fortner.aspx)
I-CARES Career Development Associate Professor - Energy, Environmental & Chemical Engineering
PhD, Rice University
John Fortner's research is primarily focused on advancing water-related technologies and engineering novel material interfaces as they relate to critical environmental-based health, security and energy challenges. He has extensively studied the environmental fate, (photo) reactivity and applications (e.g., novel water treatment membranes) of engineered carbon nanomaterials, including fullerenes, carbon nanotubes, and graphene-based materials.

Harold Li (https://radonc.wustl.edu/faculty/harold-li)
PhD, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany
Associate Professor - Radiation Oncology
Harold Li's research lab, funded by the NIH since 2008, develops high resolution dosimetry systems for radiation therapy dosimetry. In addition, he leads the MRgRT group in developing both experimental and computational methods for radiation therapy patient dosimetry subject to a permanent magnetic field.
Srikanth Singamaneni (https://engineering.wustl.edu/Profiles/Pages/Srikanth-Singamaneni.aspx)
Associate Professor - Mechanical Engineering & Materials Science
PhD, Georgia Institute of Technology
Professor Singamaneni's research interests include plasmonic engineering in nanomedicine (in vitro biosensing for point-of-care diagnostics, molecular bioimaging, nanotherapeutics), photovoltaics (plasmonically enhanced photovoltaic devices), surface enhanced Raman scattering (SERS) based chemical sensors with particular emphasis on the design and fabrication of unconventional and highly efficient SERS substrates, hierarchical organic/inorganic nanohybrids as multifunctional materials, bioinspired structural and functional materials, polymer surfaces and interfaces, responsive and adaptive materials and scanning probe microscopy and surface force spectroscopy of soft and biological materials.

Philip Skemer (http://eps.wustl.edu/people/phil_skemer)
Associate Professor - Earth and Planetary Sciences
Professor Skemer's research interests include mantle deformation, the formation and the dynamics of plate boundaries, and the interpretation of seismological data. The underlying motivation for his research is to understand the remarkable phenomenon of plate tectonics and its variability among the terrestrial planets. Although primarily an experimentalist, his research uses the microstructures of naturally deformed rocks to infer the importance of specific deformation processes in Earth, and then develops experiments to investigate the sensitivity of these processes to a range of deformation conditions. From these experiments, one can make predictions about rock deformation at conditions or locations that are inaccessible to direct observation.

Assistant Professors

Damena Agonafer (https://engineering.wustl.edu/Profiles/Pages/Damena-Agonafers.aspx)
Assistant Professor - Mechanical Engineering & Materials Science
PhD, University of Illinois
Professor Agonafer's research interest includes the areas of phase routing strategies for chemical separation and phase change heat transfer processes, and electrochemical storage applications. His research interest is at the intersection of thermal-fluid sciences, electrokinetics and interfacial transport phenomena, and renewable energy. His goal is to bring transformational changes in the areas related to electrochemical energy storage, cooling of high powered micro and power electronics, and water desalination by tuning and controlling solid-liquid-vapor interactions at micro/nano length scales.

Anupriya Agrawal (https://mems.wustl.edu/faculty/Pages/Anupriya-Agrawal.aspx)
Research Assistant Professor - Mechanical Engineering & Materials Science
PhD, Ohio State University
Professor Agrawal's research focuses on investigating the structure and dynamics of polymers and metallic glasses using molecular dynamics simulations. She is interested in investigating the deformation behavior of metallic glasses and composites. Her interest also lies in exploring polymer properties such as deformation behavior, diffusion of small organic molecules and ionic aggregation at large length and time scales using multi-scale models.

Philip Bai (https://eece.wustl.edu/faculty/Pages/faculty.aspx?bio=122)
Assistant Professor - Energy, Environmental & Chemical Engineering
PhD, Tsinghua University, Beijing
Professor Bai's research focuses on the development of next-generation batteries. Knowledge and tools developed in the Bai Group also apply to and benefit the design of other electrochemical energy systems like supercapacitors and fuel cells.

Alexander Barnes (http://chemistry.wustl.edu/faculty/barnes)
Assistant Professor - Chemistry
PhD, Massachusetts Institute of Technology
Magnetic resonance; dynamic nuclear polarization; structural biology; rational drug design; HIV drug design; Alzheimer's; cancer; electrical engineering; gyrotron technology; molecular biology; biophysical chemistry.

Mikhail Y. Berezin (http://dbbs.wustl.edu/faculty/Pages/faculty_bio.aspx?SID=6263)
Assistant Professor - Radiology
PhD, Moscow Institute of Oil and Gas/Institute of Organic Chemistry
Professor Berezin's research interest lies in the investigation and application of molecular excited states and their reactions for medical imaging and clinical treatment. Excited states are the cornerstone of a variety of chemical, physical, and biological phenomena. The ability to probe, investigate, and control excited states is one of the largest achievements of modern science. The lab focuses on the development of novel optically active probes ranging from small molecules to nanoparticles, and the development of optical instrumentation for spectroscopy and imaging and their applications in medicine.
Rajan Chakrabarty (https://engineering.wustl.edu/Profiles/Pages/Rajan-Chakrabarty.aspx)
Assistant Professor - Energy, Environmental & Chemical Engineering
PhD, University of Nevada, Reno
Rajan Chakrabarty’s research focuses on two distinct themes: (i) Investigating the role of atmospheric aerosols in earth’s energy balance using novel instrumentation and diagnostic techniques, and numerical models; and (ii) Understanding aerosol formation in combustion systems toward synthesis of high porosity and surface-area materials for energy applications.

Julio D’Arcy (http://www.chemistry.wustl.edu/faculty/darcy)
Assistant Professor - Chemistry
PhD, University of California, Los Angeles
The overarching goals of the D’Arcy laboratory are to discover and apply novel functional nanostructured organic and inorganic materials utilizing universal synthetic chemistry protocols that control chemical structure, nanoscale morphology, and intrinsic properties. We are interested in capacitive and pseudocapacitive nanostructured materials such as conducting polymers, metal oxides, and carbon allotropes possessing enhanced chemical and physical properties, i.e., charge carrier transport, ion transport, surface area, thermal and mechanical stability. Our concerted material discovery process is a multipronged approach; organic and inorganic nanostructured materials are synthesized via solution processing, electrochemistry, vapor phase deposition, and combinations thereof. Alternatively, we also develop self-assembly techniques that result in tailored materials.

Marcus Foston (https://engineering.wustl.edu/Profiles/Pages/Marcus-Foston.aspx)
Assistant Professor - Energy, Environmental & Chemical Engineering
PhD, Georgia Institute of Technology
Professor Foston’s research objective is to create a top tier, world-recognized research program in the research and education of emerging technologies for exploitation of lignocellulosic biomass, in particular the lignin fraction of biomass, as a sustainable source for energy, chemicals and materials production.

Erik Henriksen (https://www.physics.wustl.edu/people/henriksen_erik)
Assistant Professor - Physics
PhD, Columbia University
We are an experimental condensed matter research lab with interests primarily in the quantum electronic properties of graphene and other novel two-dimensional systems. We utilize state-of-the-art nanofabrication techniques in combination with measurements made at low temperatures and high magnetic fields to explore both the fundamental electronic structures and emergent quantum phenomena of low-dimensional materials.

Mark Meacham (https://engineering.wustl.edu/Profiles/Pages/Mark-Meacham.aspx)
Assistant Professor - Mechanical Engineering & Materials Science
PhD, Georgia Institute of Technology
Mark Meacham's research interests include microfluidics, micro-electromechanical systems (MEMS) and associated transport phenomena, with application to design, development and testing of novel energy systems and life sciences tools, from scalable micro-/nanotechnologies for improved heat and mass exchangers to MEMS-based tools for manipulation and investigation of cellular processes. He is also interested in the behavior of jets and/or droplets of complex fluids during ejection from microscopic orifices, which is critical to applications as disparate as biological sample preparation and additive manufacturing.

Rohan Mishra (https://engineering.wustl.edu/Profiles/Pages/Rohan-Mishra.aspx)
Assistant Professor - Mechanical Engineering & Materials Science
PhD, Ohio State University
In his lab at Washington University, Mishra plans to identify and develop a quantitative measure of structure-property correlations in materials, such as epitaxial thin films and materials with reduced dimensionality, using a synergistic combination of scanning transmission electron microscopy and atomic-scale theory, to create rational design of materials with properties tailored for electronic, magnetic, optical and energy applications.

Ryan Ogliore (http://physics.wustl.edu/people/ogliore_ryan)
Assistant Professor - Physics
PhD, California Institute of Technology
Professor Ogliore’s research group uses microanalytical techniques to study extraterrestrial materials in order to better understand the formation and evolution of our solar system, as well as other stars.
Bryce Sadtler (http://www.chemistry.wustl.edu/faculty/sadtler)  
Assistant Professor - Chemistry  
PhD, University of California, Berkeley  
The Sadtler research group seeks to understand and control structure-property relationships in adaptive, mesostructured materials. Through hierarchical design of the atomic composition, nanoscale morphology, and mesoscale organization of the individual components, we can direct the emergent chemical reactivity and physical properties of these complex systems. Research projects combine solution phase growth techniques to synthesize inorganic materials, external fields to control the growth and assembly of mesoscale architectures, and super-resolution imaging to provide spatiotemporal maps of the optical response and photocatalytic activity during the morphological evolution of these structures. Knowledge gained from these fundamental studies will be used to create functional materials, including plasmonic substrates that enhance absorption in thin-film semiconductors, mesostructured photocatalysts for solar fuels generation, and chemical sensors based on self-assembled photonic structures.

Simon Tang (http://www.orthoresearch.wustl.edu/content/Laboratories/3043/Simon-Tang/Tang-Lab/Overview.aspx)  
Assistant Professor - Orthopaedics  
PhD, Rensselaer Polytechnic Institute  
With the overall theme of understanding the biological regulation of skeletal matrix quality, our research group integrates engineering and biology approaches for (1) understanding the effect of disease mechanisms on the structure-function relationships of skeletal tissues and (2) developing of translatable therapeutic and regenerative strategies for these diseases. The investigation of these scientific questions includes the application of finite element analyses, multiscale tissue mechanics, and the functional imaging of skeletal tissues for regenerative medicine with in vitro and in vivo biological systems.

Elijah Thimsen (https://engineering.wustl.edu/Profiles/Pages/Elijah-Thimsen.aspx)  
Assistant Professor - Energy, Environmental & Chemical Engineering  
PhD, Washington University  
The Interface Research Group focuses on advanced gas-phase synthesis of nanomaterials for energy applications. We are currently exploring nonthermal plasma synthesis and atomic layer deposition (ALD). The goal is to discover and then understand useful interfacial phenomena. Examples of applications we are currently interested in are: transparent conducting oxides, photovoltaics, lithium-sulfur batteries, and coatings for high-temperature combustion.

Patricia Weisensee (https://mems.wustl.edu/faculty/Pages/default.aspx?bio=112)  
Assistant Professor - Mechanical Engineering & Materials Science  
PhD, University of Illinois at Urbana-Champaign  
Patricia Weisensee's work focuses on the interaction of liquids and micro- and nanostructured solids. Her research is both fundamental and applied and spans a wide range of applications in the fluid and thermal sciences, from droplet impact over phase change heat transfer to electronics cooling.

Degree Requirements  
Interdisciplinary PhD in Materials Science & Engineering  
To earn a PhD degree, students must complete the Graduate School requirements, along with specific program requirements. Courses include:

- Four IMSE Core Courses (12 academic credits)

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
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<tbody>
<tr>
<td>MEMS 5608</td>
<td>Introduction to Polymer Science and Engineering</td>
<td>3</td>
</tr>
<tr>
<td>Physics 537</td>
<td>Kinetics of Materials</td>
<td>3</td>
</tr>
<tr>
<td>EECE 502</td>
<td>Advanced Thermodynamics in EECE</td>
<td>3</td>
</tr>
<tr>
<td>Chem 465</td>
<td>Solid-State and Materials Chemistry</td>
<td>3</td>
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<tr>
<td>or Physics 472</td>
<td>Solid State Physics</td>
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Total Units 12

- IMSE 500 First-Year Research Rotation (3 academic credits)
- Three courses (9 credits) from a preapproved list of Materials Science & Engineering electives
- A minimum of 12 credits of graduate-level technical elective courses in Mathematics or any science or engineering department, to reach a total of at least 36 academic credits
  - A maximum of 3 credits of IMSE 502 Independent Study will be permitted toward the free electives requirement.
  - A maximum of 3 credits of IMSE 505 Material Science Journal Club will be permitted toward this requirement.
  - 400-level courses not included on the preapproved list of Materials Science & Engineering electives must be approved by the Graduate Studies Committee.
- A maximum of 12 credits of 400-level courses may be applied to the required 36 academic credits. Undergraduate-only courses (below the 400 level) are generally not permitted by the Graduate School and may not be used to fulfill this requirement.
- Enroll in and satisfactorily complete IMSE 501 IMSE Graduate Seminar every semester
- Successfully complete 18-36 credits of IMSE 600 Doctoral Research
- Complete research ethics training by the end of the third semester
- Maintain a GPA of at least 3.0 for all graded courses
  - Have no more than one grade of B- or below in a core course or Materials Science & Engineering elective
- Successfully complete teaching requirement
  - Attend 2+ Teaching Center Workshops
  - Have 15 units of teaching experience
- Pass the IMSE Qualifying Examination (oral & written)
- Identify an IMSE faculty member willing and able to support their thesis research on a materials-related topic
- Maintain satisfactory research progress on a topic in materials science, as determined by the thesis adviser and Mentoring Committee
- Successfully complete the Thesis Proposal and Presentation, with approval from the Thesis Examination Committee
- Successfully complete and defend a PhD Dissertation, with final approval from the Thesis Examination Committee

Failure to meet these requirements will result in dismissal from the program.

**Course Plan**

**Year 1**

**Fall Semester (13 credits)**
- Solid-State and Materials Chemistry (Chem 465) or Elective
- Advanced Thermodynamics in EECE (EECE 502)
- Introduction to Polymer Science and Engineering (MEMS 5608)
- Elective (optional)
- IMSE Graduate Seminar (IMSE 501)

**Spring Semester (13 credits)**
- Solid State Physics (Physics 472) or Elective
- Kinetics of Materials (Physics 537)
- Elective (optional)
- IMSE First-Year Research Rotation (IMSE 500)
- IMSE Graduate Seminar (IMSE 501)

**Summer**
- Begin thesis research
- Prepare for Qualifying Exam (August)
  - Written document and oral presentation on research rotation
  - Oral exam on fundamentals from core courses

**Years 2 and beyond**
- Electives (discuss with PhD adviser)
- IMSE Graduate Seminar (IMSE 501)

- Doctoral Research (IMSE 600)
- Teaching Requirement
  - Attend 2+ Teaching Center Workshops
  - 15 units of Mentored Teaching Experience
- Annual (or more frequent) meetings with Faculty Mentoring Committee
- Thesis proposal and presentation (fifth semester)
- Dissertation and oral defense