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 (e.g., chemistry, physics) play a central role in developing the fundamental knowledge that is needed to design materials for a variety of engineering applications (e.g., mechanical engineering, electrical engineering, biomedical engineering). Building on training that spans from fundamental to applied sciences, materials scientists and engineers integrate this fundamental knowledge 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. The IMSE brings together a diverse group of faculty from departments in Arts & Sciences, the McKelvey School of Engineering, and the School of Medicine. The IMSE also oversees shared research and instrument facilities, develops partnerships with industry and national laboratories, and facilitates outreach activities.

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

- Biomedical, bio-derived and bio-inspired materials
- Materials for energy generation, harvesting and storage
- Materials for environmental technologies and sustainability
- Materials for sensors, imaging and optoelectronics
- Nanomaterials and glasses
- Low-dimensional and quantum materials

Contact: Beth Gartin
Phone: 314-935-7191
Email: bgartin@wustl.edu
Website: http://imse.wustl.edu

Faculty

Director

Katharine M. Flores (https://engineering.wustl.edu/faculty/Katharine-Flores.html)
Professor, Mechanical Engineering & Materials Science
PhD, Stanford University

Professor Flores' primary research interest is the mechanical behavior of high-performance structural materials, with particular emphasis on understanding structure-processing-property relationships in bulk metallic glasses and their composites.

Professors

The Stifel & Quinette Jens Professor of Environmental Engineering Science
PhD, University of California, Davis
Dr. 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.

William Buhro (https://chemistry.wustl.edu/people/william-buhro/)
George E. Pake Professor in Arts & Sciences and Department Chair, Chemistry
PhD, University of California, Los Angeles
Professor Buhro's areas of interest include 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
Professor 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.

Guy Genin (https://engineering.wustl.edu/Profiles/Pages/Guy-Genin.aspx)
Harold and Kathleen Faught Professor of Mechanical Engineering
PhD, Harvard University
Guy Genin studies interfaces and adhesion in nature, physiology, and engineering. His current research focuses on interfaces between tissues at the attachment of tendon to bone, between cells in cardiac fibrosis, and between protein structures at the periphery of plant and animal cells.
Jianjun Guan (https://engineering.wustl.edu/faculty/Jianjun-Guan.html)
Professor, Mechanical Engineering and Materials Science
PhD, Zhejiang University

Professor Guan's research interests are in biomimetic biomaterials synthesis and scaffold fabrication; bioinspired modification of biomaterials; injectable and highly flexible hydrogels; bioimageable polymers for MRI and EPR imaging and oxygen sensing; mathematical modeling of scaffold structural and mechanical properties; stem cell differentiation; neural stem cell transplantation for brain tissue regeneration; and bone and cardiovascular tissue engineering.

Sophia E. Hayes (https://chemistry.wustl.edu/people/sophia-e-hayes/)
Professor, Chemistry
PhD, University of California, Santa Barbara

Professor Hayes studies physical inorganic chemistry; materials chemistry; solid-state NMR; magnetic resonance; optically-pumped NMR; semiconductors; quantum wells; magneto-optical spectroscopy; quadrupolar NMR of thin films and tridecameric metal hydroxide clusters and thin films; carbon capture, utilization and storage; CO₂ geosequestration; CO₂ capture; in situ NMR; and metal carbonate formation.

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

Professor Kelton is involved in the study and production of titanium-based quasicrystals and related phases; fundamental investigations of time-dependent nucleation processes; modeling of oxygen precipitation in single crystal silicon; structure of amorphous materials; relation between structure and nucleation barrier; and hydrogen storage in quasicrystals.

Harold Li (https://radonc.wustl.edu/faculty/harold-li/)
Associate Professor, Radiation Oncology
PhD, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

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.

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, ARPA-E, 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).

Srikanth Singamaneni (https://engineering.wustl.edu/Profiles/Pages/Srikanth-Singamaneni.aspx)
The Lilyan & E. Lisle Hughes 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.

Lan Yang (https://engineering.wustl.edu/faculty/Lan-Yang.html)
Edwin H. & Florence G. Skinner Professor, Electrical & Systems Engineering
PhD, California Institute of Technology

Professor Yang is a fellow of The Optical Society. Her research interests include fabrication, characterization and fundamental understanding of advanced nano-/micro-photonic devices with outstanding optical properties or novel features for unconventional control of light flow. Her group focuses on silicon-chip–based, ultra-high-quality micro-resonators and their applications for sensing, lasing, nonlinear optics, environmental monitoring, biomedical research and communication.

Associate Professors

Mikhail Y. Berezin (http://dbbs.wustl.edu/faculty/Pages/faculty_bio.aspx?SID=6263)
Associate Professor, Radiology
PhD, Moscow Institute of Oil and Gas/Institute of Organic Chemistry

Dr. Berezin’s 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 using knowledge of excited states. The lab’s research interest lies in the investigation and application of molecular excited states and their reactions for medical imaging and clinical treatment.
Rajan Chakrabarty (https://engineering.wustl.edu/Profiles/Pages/Rajan-Chakrabarty.aspx)
Associate Professor, Energy, Environmental & Chemical Engineering
PhD, University of Nevada, Reno

Professor Chakrabarty currently leads the Complex Aerosol Systems Research Laboratory (https://sites.google.com/view/chakrabarty-group/) at Washington University, which works at the forefront of addressing grand challenges associated with complex environmental systems. The lab's current research focus is in characterizing the dynamics and properties of the various “agents” that undergo multiple interactions to give rise to emergent behavior in environmental systems.

Marcus Foston (https://engineering.wustl.edu/faculty/Marcus-Foston.html)
Associate Professor, Energy, Environmental & Chemical Engineering
PhD, Georgia Institute of Technology

Professor Foston's research program seeks to develop innovative and novel routes to exploit and utilize lignocellulosic biomass by taking advantage of materials involved in industries such as agriculture, papermaking, and forestry products.

Simon Tang (http://www.orthoresearch.wustl.edu/content/Laboratories/3043/Simon-Tang/Tang-Lab/Overview.aspx)
Associate Professor, Orthopaedics
PhD, Rensselaer Polytechnic Institute

Professor Tang's research program integrates musculoskeletal bioengineering and regenerative medicine to discover novel and new therapies for precision medicine and rehabilitation. Musculoskeletal conditions including low back pain, osteoporosis, and osteoarthritis afflict nearly 90% of all Americans.

Assistant Professors

Damena Agonafer (https://engineering.wustl.edu/faculty/Damena-Agunafer.html)
Assistant Professor, Mechanical Engineering & Materials Science
PhD, University of Illinois

Professor Agonafer’s research interest is at the intersection of thermal-fluid sciences, interfacial transport phenomena, and renewable energy. He is focused on developing novel materials and systems for the thermal management of power and microelectronic systems as well as for thermochemical and electrochemical energy storage applications. His goal is to achieve transformational changes in technologies by tuning and controlling solid-liquid-vapor interactions at micro/nano length scales.

Sang-Hoon Bae
Assistant Professor, Mechanical Engineering & Materials Science
PhD, University of California, Los Angeles

Professor Bae’s research group focuses on tackling the challenges in materials science with thermodynamics, kinetics and solid-state physics.

Peng Bai (https://engineering.wustl.edu/faculty/Peng-Bai.html)
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.

Julio D'Arcy (https://chemistry.wustl.edu/people/julio-m-darcy/)
Assistant Professor, Chemistry
PhD, University of California, Los Angeles

The overarching goals of Julio D’Arcy's 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.

Erik Henriksen (https://physics.wustl.edu/people/erik-henriksen/)
Assistant Professor, Physics
PhD, Columbia University

Professor Henriksen's lab research is centered on the properties of electrons confined to two dimensions. This remarkable system has yielded a tremendous amount of interesting and important physics over the past several decades, from the integer and fractional quantum Hall effects to the groundbreaking discoveries of graphene and other atomically thin crystals and especially to the recent realization of the topological nature of the electronic structure of a surprising number of materials both novel and familiar.

Nathaniel Huebsch (https://imse.wustl.edu/people/nathaniel-huebsch/)
Assistant Professor, Biomedical Engineering

Professor Huebsch's research focus is in basic and translational stem cell mechanobiology, with specific focus on hydrogels to control cell-mediated tissue repair and three-dimensional, iPSC-based heart-in-a-dish models to study the influence of mechanical loading and genetics on arrhythmia and contractility.
Matthew Lew (https://engineering.wustl.edu/faculty/ Matthew-Lew.html)
Assistant Professor, Electrical & Systems Engineering
PhD, Stanford University

Professor Lew and his students build advanced imaging systems to study biological and chemical systems at the nanoscale, leveraging innovations in applied optics, signal and image processing, design optimization, and physical chemistry. Their advanced nanoscopes (microscopes with nanometer resolution) visualize the activity of individual molecular machines inside and outside living cells. Examples of new technologies developed in the Lew Lab include (1) using tiny fluorescent molecules as sensors that can detect amyloid proteins; (2) designing new "lenses" to create imaging systems that can visualize how molecules move and tumble; and (3) new imaging software that minimizes artifacts in super-resolution images.

Matthew R. MacEwan
Assistant Professor, Neurosurgery
PhD, Washington University in St. Louis

Dr. MacEwan is interested in the development and validation of electrode/tissue interfaces for regenerative and rehabilitative applications.

Mark Meacham (https://engineering.wustl.edu/faculty/Mark Meacham.html)
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 the design, development, and testing of novel energy systems and life sciences tools, from scalable micro-/nano-technologies for improved heat and mass exchangers to MEMS-based tools for the 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/faculty/Rohan Mishra.html)
Assistant Professor, Mechanical Engineering & Materials Science
PhD, Ohio State University

Rohan Mishra’s research interest is to develop quantitative structure-property correlations in materials starting from the atomic scale. To develop such correlations, his group synergistically combines electronic structure calculations with atomic-resolution electron microscope imaging and spectroscopy. The end goal is the rational design of materials with properties tailored for electronic, optical, magnetic and energy applications. Current research topics include perovskite materials for photovoltaic and optoelectronic applications, novel electrocatalysts, oxidizers and wide-bandgap semiconductors.

Ryan Ogliore (https://physics.wustl.edu/people/ryan ogliore/)
Assistant Professor, Physics
PhD, California Institute of Technology

Professor Ogliore's research group uses microanalytical techniques to study extraterrestrial materials to better understand the formation and evolution of our solar system as well as other stars.

Sheng Ran
Assistant Professor, Physics
PhD, Iowa State University

Professor Ran’s research aims to realize and understand exotic states of quantum materials using combined techniques of bulk crystal synthesis, electric and thermal transport measurements under extreme temperature, pressure and magnetic field conditions, and neutron and high-energy X-ray scattering.

Jai Rudra (https://engineering.wustl.edu/faculty/Jai Rudra.html)
Assistant Professor, Biomedical Engineering
PhD, Louisiana Tech University

Jai Rudra’s lab is interested in the development of nanoscale biomaterials such as nanofibers, nanoparticles, virus-like particles, and hydrogels for engaging the immune system to induce protective antibody and cell-mediated immune responses against diseases such as tuberculosis, melanoma and flavivirus infections (i.e., West Nile and Zika). He is also investigating the development of vaccines against drugs of addiction such as cocaine. Biomaterials immunoengineering is a multidisciplinary field that lies at the intersection of materials science, chemistry, immunology and vaccinology. Professor Rudra’s lab collaborates with virologists, immunologists, and clinicians not only to develop synthetic vaccination platforms but also to understand how biomaterials interact with the immune system and continue to develop novel materials and creative tools to tackle multidisciplinary problems in vaccine development and immunotherapy.

Bryce Sadtler (https://chemistry.wustl.edu/people/bryce 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.

Elijah Thimsen (https://engineering.wustl.edu/faculty/Elijah-Thimsen.html)
Assistant Professor, Energy, Environmental & Chemical Engineering
PhD, Washington University
The Interface Research Group led by Elijah Thimsen focuses on advanced gas-phase synthesis methods that operate very far away from local equilibrium (e.g., low temperature plasma). Such methods are capable of creating beyond equilibrium materials, which represent one of the greatest opportunities for synthesis science. Examples of applications currently being pursued by the Interface Research Group are advanced lightweight aerospace composite materials, optoelectronic semiconductor nanostructures, analog low-power artificial intelligence, and high-energy density fuel synthesis from renewable resources.

Assistant Professor, Electrical and Systems Engineering
PhD, University of Southern California
Professor Wang's interests include two-dimensional semiconductor nanoelectronics and optoelectronics, stretchable electronics, printed electronics, sensors and actuators.

Patricia Weisensee (https://engineering.wustl.edu/faculty/Patricia-Weisensee.html)
Assistant Professor, Mechanical Engineering & Materials Science
PhD, University of Illinois at Urbana-Champaign
Professor Weisensee’s work focuses on understanding the interplay of fluid dynamics, heat transfer, and liquid-solid interactions of droplets and other multi-phase systems. Practical applications of interest are phase change heat transfer for thermal management, thermal storage, water harvesting, metallic additive manufacturing, and droplet interactions with biological and natural systems.

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 the following:

- Four IMSE Core Courses (12 credits)

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEMS 5610</td>
<td>Quantitative Materials Science &amp; 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>
</tr>
<tr>
<td>or Physics 472</td>
<td>Solid State Physics</td>
<td></td>
</tr>
</tbody>
</table>

Total Units: 12

- IMSE 500 First-Year Research Rotation (3 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.
  - Any 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 toward 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.
- IMSE 501 IMSE Graduate Seminar every semester of full-time enrollment
- 18 to 36 credits of IMSE 600 Doctoral Research (Students must identify an IMSE faculty member willing and able to support their thesis research on a materials-related topic.)
- Students must maintain a grade-point average of at least 3.0 for all graded courses and have no more than one grade of B- or below in a core course or a Materials Science & Engineering elective.

Additional program requirements include the following:
• Complete research ethics training by the end of the third semester
• Successfully complete teaching requirements
  • Attend two or more Teaching Center workshops
  • Complete 15 units of mentored teaching experience
• Pass the IMSE Qualifying Examination (oral and written components)
• Maintain satisfactory research progress on a topic in materials science, as determined by the thesis adviser and the 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)
• Advanced Thermodynamics in EECE (EECE 502)
• Quantitative Materials Science & Engineering (MEMS 5610)
• IMSE Research Rotation (IMSE 500)
• IMSE Graduate Seminar (IMSE 501)
• Elective (optional)

Spring Semester (13 credits)
• Solid-State and Materials Chemistry (Chem 465)
• Kinetics of Materials (Physics 537)
• IMSE First-Year Research Rotation (IMSE 500)
• IMSE Graduate Seminar (IMSE 501)
• Elective (optional)

Summer
• Begin thesis research
• Prepare for IMSE Qualifying Examination (August)
  • Written document and oral presentation on research rotation
  • Oral examination on fundamentals from core courses

Years 2 and Beyond
• Electives (discuss with PhD adviser)
• IMSE Graduate Seminar (IMSE 501)
• Doctoral Research (IMSE 600)
• Teaching requirements
  • Attend two or more Teaching Center workshops
  • Complete 15 units of mentored teaching experience
  • Regular meetings (at least twice per year) with the faculty mentoring committee
  • Thesis proposal and presentation (fifth semester)
  • Dissertation and oral defense