

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) frequently 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 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. 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 facilities, 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 and imaging
- Nanomaterials and glasses
- Optoelectronic, low-dimensional, and quantum materials

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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 structural materials, with particular emphasis on understanding structure-processing-property relationships in bulk metallic glasses and their composites.

Professors

Richard Axelbaum (<https://engineering.wustl.edu/faculty/Richard-Axelbaum.html>)

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.

Pratim Biswas (<https://engineering.wustl.edu/faculty/Pratim-Biswas.html>)

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 (<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

Shantanu Chakrabartty's research explores new frontiers in unconventional analog computing techniques using silicon and hybrid substrates. His objective is to approach the 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.

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 (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; 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/>)

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.

Vijay Ramani (<https://engineering.wustl.edu/Profiles/Pages/Vijay-Ramani.aspx>)

Roma B. & Raymond H. Wittcoff 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).

Srikanth Singamaneni (<https://engineering.wustl.edu/Profiles/Pages/Srikanth-Singamaneni.aspx>)

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's research interests are fabrication, characterization, and fundamental understanding of advanced nano-/micro-phonic 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 nano-/micro-photonic devices from advanced materials with desired properties.

Associate Professors

Philip Skemer (<https://eps.wustl.edu/people/philip-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 he 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/faculty/Damena-Agonafer.html>)

Assistant Professor - Mechanical Engineering & Materials Science
PhD, University of Illinois

Professor Agonafer's research interests include the areas of phase routing strategies for chemical separation and phase change heat transfer processes as well as 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.

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.

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 interests lie 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 as well as 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: (1) investigating the role of atmospheric aerosols in earth's energy balance using novel instrumentation, diagnostic techniques and numerical models; and (2) understanding aerosol formation in combustion systems toward the synthesis of high-porosity and surface-area materials for energy applications.

Julio D'Arcy (<https://chemistry.wustl.edu/people/julio-m-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/faculty/Marcus-Foston.html>)

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 the exploitation of lignocellulosic biomass — in particular, the lignin fraction of biomass — as a sustainable source for energy, chemicals and materials production.

Erik Henriksen (<https://physics.wustl.edu/people/erik-henriksen/>)

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.

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 3D heart-on-a-chip models derived from human-induced pluripotent stem cells.

Matthew Lew (<https://engineering.wustl.edu/faculty/Matthew-Lew.html>)

Assistant Professor - Electrical & Systems Engineering

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.

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

In his lab at Washington University, Professor Mishra plans to identify and develop a quantitative measure of structure-property correlations in materials (e.g., epitaxial thin films and materials with reduced dimensionality) using a synergistic combination of scanning transmission electron microscopy and atomic-scale theory to create the rational design of materials with properties tailored for electronic, magnetic, optical and energy applications.

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 in order to better understand the formation and evolution of our solar system as well as other stars.

Jai Rudra (<https://engineering.wustl.edu/faculty/Jai-Rudra.html>)

Assistant Professor - Biomedical Engineering

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.

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 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/faculty/Elijah-Thimsen.html>)

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. The goal is to discover and then understand useful interfacial phenomena. Examples of applications that we are currently interested in include transparent conducting oxides, photovoltaics, lithium-sulfur batteries, and coatings for high-temperature combustion.

Chuan Wang (<https://engineering.wustl.edu/faculty/Chuan-Wang.html>)

Assistant Professor - Electrical and Systems Engineering

Chuan Wang's focus areas of research include (1) flexible and stretchable electronics for displaying, sensing and energy harvesting applications; (2) low-cost additive manufacturing of flexible and stretchable electronics using inkjet printing; and (3) high-performance nanoelectronics and optoelectronics using 2D semiconductors.

Patricia Weisensee (<https://engineering.wustl.edu/faculty/Patricia-Weisensee.html>)

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 nano-structured 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 the following:

- Four IMSE Core Courses (12 credits)

Code	Title	Units
MEMS 5610	Quantitative Materials Science & Engineering	3
Physics 537	Kinetics of Materials	3
EECE 502	Advanced Thermodynamics in EECE	3
Chem 465	Solid-State and Materials Chemistry	3
	or Physics 472 Solid State Physics	
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 First-Year 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