MATERIALS SCIENCE & ENGINEER (MATSCI)

MATSCI 100. Undergraduate Independent Study. 1-3 Unit.
Independent study in materials science under supervision of a faculty member.

MATSCI 10SC. Diamonds from Peanut Butter: Material Technologies and Human History. 2 Units.
Technological importance of materials in history is captured in names: the Stone Age, Bronze Age, Iron Age, and now the Information Age or the Silicon Age. How materials have played, and continue to play, pivotal roles in the development of new technologies.

MATSCI 12SC. Lenses to Remove Limits: Microscopy. 2 Units.
Sigmund Freud once wrote 'With every tool, man is perfecting his own organs or removing the limits to their functioning...by means of the microscope he overcomes the limits of visibility set by the structure of his retina.' This course will describe the science behind and impact of microscopy. Lectures will cover both basic and advanced techniques in optical microscopy, electron microscopy, and atomic force microscopy, giving ample time to discuss the science behind the 2014 and 2017 Nobel Prizes (awarded for super-resolution and cryo-electron microscopy, respectively). Laboratory work will give students hands-on experience visualizing the world, both natural or engineered, with ultra-high resolution. Field trips to biotech, energy and computing industries will supplement lectures, illustrating how microscopy forms the foundation for many commercial technologies and products. We will also discuss the future of imaging and microscopy, including the "hardware" needed to push resolution limits as well as the "software" (i.e., AI, VR) that enhances the visualization experience.

MATSCI 142. Quantum Mechanics of Nanoscale Materials. 4 Units.
Introduction to quantum mechanics and its application to the properties of materials. No prior background beyond a working knowledge of calculus and high school physics is presumed. Topics include: the Schrodinger equation and applications to understanding of the properties of quantum dots, semiconductor heterostructures, nanowires, and bulk solids. Tunneling processes and applications to nanoscale devices; the scanning tunneling microscope, and quantum cascade lasers. Simple models for the electronic properties and band structure of materials including semiconductors, insulators and metals and applications to semiconductor devices. Time-dependent perturbation theory and interaction of light with materials with applications to laser technology. Recommended: ENGR 50 or equivalent introductory materials science course. (Formerly 157).

MATSCI 143. Materials Structure and Characterization. 4 Units.
Students will study the theory and application of characterization techniques used to examine the structure of materials at the nanoscale. Students will learn to classify the structure of materials such as semiconductors, ceramics, metals, and nanotubes according to the principles of crystallography. Methods used widely in academic and industrial research, including X-ray diffraction and electron microscopy, will be demonstrated along with their application to the analysis of nanostructures. Prerequisites: E-50 or equivalent introductory materials science course. (Formerly 153).

MATSCI 144. Thermodynamic Evaluation of Green Energy Technologies. 4 Units.
Understand the thermodynamics and efficiency limits of modern green technologies such as carbon dioxide capture from air, fuel cells, batteries, and solar-thermal power. Recommended: ENGR 50 or equivalent introductory materials science course. (Formerly 154).

MATSCI 145. Kinetics of Materials Synthesis. 4 Units.
The science of synthesis of nanometer scale materials. Examples including solution phase synthesis of nanoparticles, the vapor-liquid-solid approach to growing nanowires, formation of mesoporous materials from block-copolymer solutions, and formation of photonic crystals. Relationship of the synthesis phenomena to the materials science driving forces and kinetic mechanisms. Materials science concepts including capillarity, Gibbs free energy, phase diagrams, and driving forces. Prerequisites: MatSci 144. (Formerly 155).

MATSCI 150. Undergraduate Research. 3-6 Units.
Participation in a research project.

MATSCI 151. Microstructure and Mechanical Properties. 3-4 Units.
Primarily for students without a materials background. Mechanical properties and their dependence on microstructure in a range of engineering materials. Elementary deformation and fracture concepts, strengthening and toughening strategies in metals and ceramics. Topics: dislocation theory, mechanisms of hardening and toughening, fracture, fatigue, and high-temperature creep. Undergraduates register in 151 for 4 units; graduates register for 251 in 3 units.
Same as: MATSCI 251

MATSCI 152. Electronic Materials Engineering. 4 Units.
Materials science and engineering for electronic device applications. Kinetic molecular theory and thermally activated processes; band structure; electrical conductivity of metals and semiconductors; intrinsic and extrinsic semiconductors; elementary p-n junction theory; operating principles of light emitting diodes, solar cells, thermoelectric coolers, and transistors. Semiconductor processing including crystal growth, ion implantation, thin film deposition, etching, lithography, and nanomaterials synthesis.

MATSCI 156. Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution. 3-4 Units.
Operating principles and applications of emerging technological solutions to the energy demands of the world. The scale of global energy usage and requirements for possible solutions. Basic physics and chemistry of solar cells, fuel cells, and batteries. Performance issues, including economics, from the ideal device to the installed system. The promise of materials research for providing next generation solutions. Undergraduates register in 156 for 4 units; graduates register in 256 for 3 units. Prerequisites: MATSCI 145 and 152 or equivalent coursework in thermodynamics and electronic properties.

MATSCI 158. Soft Matter in Biomedical Devices, Microelectronics, and Everyday Life. 4 Units.
The relationships between molecular structure, morphology, and the unique physical, chemical, and mechanical behavior of polymers and other types of soft matter are discussed. Topics include methods for preparing synthetic polymers and examination of how enthalpy and entropy determine conformation, solubility, mechanical behavior, microphase separation, crystallinity, glass transitions, elasticity, and linear viscoelasticity. Case studies covering polymers in biomedical devices and microelectronics will be covered. Recommended: ENGR 50 and Chem 31A or equivalent.
Same as: BIOE 158, CHEMENG 160

MATSCI 159Q. Japanese Companies and Japanese Society. 3 Units.
Preference to sophomores. The structure of a Japanese company from the point of view of Japanese society. Visiting researchers from Japanese companies give presentations on their research enterprise. The Japanese research ethic. The home campus equivalent of a Kyoto SCTI course. Same as: ENGR 159Q
MATSCI 160. Nanomaterials Laboratory. 4 Units.
Preference to sophomores and juniors. Hands-on approach to synthesis and characterization of nanoscale materials. How to make, pattern, and analyze the latest nanotech materials, including nanoparticles, nanowires, and self-assembled monolayers. Techniques such as soft lithography, self-assembly, and surface functionalization. The VLS mechanism of nanowire growth, nanoparticle size control, self-assembly mechanisms, and surface energy considerations. Laboratory projects. Enrollment limited to 24.

MATSCI 161. Energy Materials Laboratory. 3-4 Units.
A material that is currently being used in a cutting edge energy-related device such as a solar cell, battery or smart window will be thoroughly characterized throughout the quarter. Fabrication techniques could include electroplating, spin coating and thermal evaporation. There will be an emphasis in this course on characterization methods such as scanning electron microscopy, x-ray photoelectron spectroscopy, atomic force microscopy, optical microscopy, four-point probe measurements of conductivity, visible absorption and reflection spectroscopy and electrochemical measurements (cyclic voltammetry). Devices will be fabricated and their performance will be tested. In this Writing in the Major course, students will put together all of the data they collect during the quarter into a final paper. Undergraduates register for 161 for 4 units; graduates register for 171 for 3 units. Prerequisites: MATSCI 143 or equivalent course in materials characterization. Same as: MATSCI 171

MATSCI 162. X-Ray Diffraction Laboratory. 3-4 Units.
Experimental x-ray diffraction techniques for microstructural analysis of materials, emphasizing powder and single-crystal techniques. Diffraction from epitaxial and polycrystalline thin films, multilayers, and amorphous materials using medium and high resolution configurations. Determination of phase purity, crystallinity, relaxation, stress, and texture in the materials. Advanced experimental x-ray diffraction techniques: reciprocal lattice mapping, reflectivity, and grazing incidence diffraction. Enrollment limited to 20. Undergraduates register for 162 for 4 units; graduates register for 172 for 3 units. Prerequisites: MATSCI 143 or equivalent course in materials characterization. Same as: MATSCI 172, PHOTON 172

MATSCI 163. Mechanical Behavior Laboratory. 3-4 Units.
Technologically relevant experimental techniques for the study of the mechanical behavior of engineering materials in bulk and thin film form, including tension testing, nanoindentation, and wafer curvature stress analysis. Metallic and polymeric systems. In addition to regularly scheduled lecture (M/W), this course includes a three-hour lab session every other week (T/W/Th). Register for lecture section in addition to one lab section. Undergraduates register for 163 in 4 units; graduates register in 173 for 3 units. Same as: MATSCI 173

MATSCI 164. Electronic and Photonic Materials and Devices Laboratory. 3-4 Units.
Lab course. Current electronic and photonic materials and devices. Device physics and micro-fabrication techniques. Students design, fabricate, and perform physical characterization on the devices they have fabricated. Established techniques and materials such as photolithography, metal evaporation, and Si technology; and novel ones such as soft lithography and organic semiconductors. Prerequisite: MATSCI 152 or 199 or consent of instructor. Undergraduates register in 164 for 4 units; graduates register in 174 for 3 units. Students are required to sign up for lecture and one lab section. Same as: MATSCI 174

MATSCI 165. Nanoscale Materials Physics Computation Laboratory. 3-4 Units.
Computational exploration of fundamental topics in materials science using Java-based computation and visualization tools. Emphasis is on the atomic-scale origins of macroscopic materials phenomena. Simulation methods include molecular dynamics and Monte Carlo with applications in thermodynamics, kinetics, and topics in statistical mechanics. Undergraduates register for 165 for 4 units; graduates register for 175 for 3 units. Prerequisites: Undergraduate physics and MATSCI 144 or equivalent coursework in thermodynamics. MATSCI 145 recommended. Same as: MATSCI 175

MATSCI 166. X-Ray Diffraction Laboratory. 3-4 Units.
Experimental x-ray diffraction techniques for microstructural analysis of materials, emphasizing powder and single-crystal techniques. Diffraction from epitaxial and polycrystalline thin films, multilayers, and amorphous materials using medium and high resolution configurations. Determination of phase purity, crystallinity, relaxation, stress, and texture in the materials. Advanced experimental x-ray diffraction techniques: reciprocal lattice mapping, reflectivity, and grazing incidence diffraction. Enrollment limited to 20. Undergraduates register for 162 for 4 units; graduates register for 172 for 3 units. Prerequisites: MATSCI 143 or equivalent course in materials characterization. Same as: MATSCI 161

MATSCI 167. X-Ray Diffraction Laboratory. 3-4 Units.
Experimental x-ray diffraction techniques for microstructural analysis of materials, emphasizing powder and single-crystal techniques. Diffraction from epitaxial and polycrystalline thin films, multilayers, and amorphous materials using medium and high resolution configurations. Determination of phase purity, crystallinity, relaxation, stress, and texture in the materials. Advanced experimental x-ray diffraction techniques: reciprocal lattice mapping, reflectivity, and grazing incidence diffraction. Enrollment limited to 20. Undergraduates register for 162 for 4 units; graduates register for 172 for 3 units. Prerequisites: MATSCI 143 or equivalent course in materials characterization. Same as: MATSCI 162, PHOTON 172

MATSCI 168. Mechanical Behavior Laboratory. 3-4 Units.
Technologically relevant experimental techniques for the study of the mechanical behavior of engineering materials in bulk and thin film form, including tension testing, nanoindentation, and wafer curvature stress analysis. Metallic and polymeric systems. In addition to regularly scheduled lecture (M/W), this course includes a three-hour lab session every other week (T/W/Th). Register for lecture section in addition to one lab section. Undergraduates register for 163 in 4 units; graduates register in 173 for 3 units. Same as: MATSCI 173

MATSCI 169. Electronic and Photonic Materials and Devices Laboratory. 3-4 Units.
Lab course. Current electronic and photonic materials and devices. Device physics and micro-fabrication techniques. Students design, fabricate, and perform physical characterization on the devices they have fabricated. Established techniques and materials such as photolithography, metal evaporation, and Si technology; and novel ones such as soft lithography and organic semiconductors. Prerequisite: MATSCI 152 or 199 or consent of instructor. Undergraduates register in 164 for 4 units; graduates register in 174 for 3 units. Students are required to sign up for lecture and one lab section. Same as: MATSCI 174
MATSCI 175. Nanoscale Materials Physics Computation Laboratory. 3-4 Units.
Computational exploration of fundamental topics in materials science using Java-based computation and visualization tools. Emphasis is on the atomic-scale origins of macroscopic materials phenomena. Simulation methods include molecular dynamics and Monte Carlo with applications in thermodynamics, kinetics, and topics in statistical mechanics. Undergraduates register for 165 for 4 units; graduates register for 175 for 3 units. Prerequisites: Undergraduate physics and MATSCI 144 or equivalent coursework in thermodynamics. MATSCI 145 recommended. Same as: MATSCI 165

MATSCI 190. Organic and Biological Materials. 3-4 Units.
Unique physical and chemical properties of organic materials and their uses. The relationship between structure and physical properties, and techniques to determine chemical structure and molecular ordering. Examples include liquid crystals, dendrimers, carbon nanotubes, hydrogels, and biopolymers such as lipids, protein, and DNA. Prerequisite: Thermodynamics and ENGR 50 or equivalent. Undergraduates register for 190 for 4 units; graduates register for 210 for 3 units. Same as: MATSCI 210

MATSCI 192. Materials Chemistry. 3-4 Units.
An introduction to the fundamental physical chemical principles underlying materials properties. Beginning from basic quantum chemistry, students will learn how the electronic configuration of molecules and solids impacts their structure, stability/reactivity, and spectra. Topics for the course include molecular symmetry, molecular orbital theory, solid-state chemistry, coordination compounds, and nanomaterials chemistry. Using both classroom lectures and journal discussions, students will gain an understanding of and be well-positioned to contribute to the frontiers of materials chemistry, ranging from solar-fuel generation to next-generation cancer treatments. Undergraduates register in 192 for 4 units; graduates register in 202 for 3 units. Same as: MATSCI 202

MATSCI 193. Atomic Arrangements in Solids. 3-4 Units.
Atomic arrangements in perfect and imperfect solids, especially important metals, ceramics, and semiconductors. Elements of formal crystallography, including development of point groups and space groups. Undergraduates register in 193 for 4 units; graduates register in 203 for 3 units. Same as: MATSCI 203

MATSCI 194. Thermodynamics and Phase Equilibria. 3-4 Units.
The principles of heterogeneous equilibria and their application to phase diagrams. Thermodynamics of solutions; chemical reactions; non-stoichiometry in compounds; first order phase transitions and metastability; thermodynamics of surfaces, elastic solids, dielectrics, and magnetic solids. Undergraduates register for 194 for 4 units; graduates register for 204 for 3 units.

MATSCI 195. Waves and Diffraction in Solids. 3-4 Units.
The elementary principals of x-ray, vibrational, and electron waves in solids. Basic wave behavior including Fourier analysis, interference, diffractions, and polarization. Examples of wave systems, including electromagnetic waves from Maxwell's equations. Diffraction intensity in reciprocal space and experimental techniques such as electron and x-ray diffraction. Lattice vibrations in solids, including vibrational modes, dispersion relationship, density of states, and thermal properties. Free electron model. Basic quantum mechanics and statistical mechanics including Fermi-Dirac and Bose-Einstein statistics. Prerequisite: MATSCI 193/203 or consent of instructor. Undergraduates register for 195 for 4 units; graduates register for 205 for 3 units. Same as: MATSCI 205, PHOTON 205

MATSCI 196. Defects in Crystalline Solids. 3-4 Units.
Thermodynamic and kinetic behaviors of 0-D (point), 1-D (line), and 2-D (surface and interface) defects in crystalline solids. Influences of these defects on the macroscopic ionic, electronic, and catalytic properties of materials, such as batteries, fuel cells, catalysts, and memory-storage devices. Prerequisite: MATSCI 193/203. Undergraduates register for 196 for 4 units; graduates register for 206 for 3 units. Same as: MATSCI 206

MATSCI 197. Rate Processes in Materials. 3-4 Units.

MATSCI 198. Mechanical Properties of Materials. 3-4 Units.
Introduction to the mechanical behavior of solids, emphasizing the relationships between microstructure and mechanical properties. Elastic, anelastic, and plastic properties of materials. The relations between stress, strain, strain rate, and temperature for plastically deformable solids. Application of dislocation theory to strengthening mechanisms in crystalline solids. The phenomena of creep, fracture, and fatigue and their controlling mechanisms. Prerequisites: MATSCI 193/203. Undergraduates register for 198 for 4 units; graduates register for 208 for 3 units. Same as: MATSCI 208

MATSCI 199. Electronic and Optical Properties of Solids. 3-4 Units.
The concepts of electronic energy bands and transporst applied to metals, semiconductors, and insulators. The behavior of electronic and optical devices including p-n junctions, MOS-capacitors, MOSFETS, optical waveguides, quantum-well lasers, light amplifiers, and metallo-dielectric light guides. Emphasis is on relationships between structure and physical properties. Elementary quantum and statistical mechanics concepts are used. Prerequisite: MATSCI 195/205 or equivalent. Undergraduates register for 199 for 4 units; graduates register for 209 for 3 units. Same as: MATSCI 209

Participation in a research project.

MATSCI 201. Applied Quantum Mechanics I. 3 Units.
Mathematics of quantum mechanics, principle of superposition, states, operators, and their applications to quantum harmonic oscillator, coherent states, and the angular momentum operator. Prerequisites: MATH 52 and 53, PHYSICS 40 or PHYSICS 41 (or PHYSICS 55 or PHYSICS 105) and PHYSICS 114 or PHYSICS 124. Same as: PHYSICS 120A

Participation in a research project.

MATSCI 203. Master's Research. 1-15 Unit.
Participation in a research project.

MATSCI 204. Master's Research. 1-15 Unit.
Participation in a research project.
MATSCI 202. Materials Chemistry. 3-4 Units.
An introduction to the fundamental physical chemical principles underlying materials properties. Beginning from basic quantum chemistry, students will learn how the electronic configuration of molecules and solids impacts their structure, stability/reactivity, and spectra. Topics for the course include molecular symmetry, molecular orbital theory, solid-state chemistry, coordination compounds, and nanomaterials chemistry. Using both classroom lectures and journal discussions, students will gain an understanding of and be well-positioned to contribute to the frontiers of materials chemistry, ranging from solar-fuel generation to next-generation cancer treatments.
Undergraduates register in 192 for 4 units; graduates register in 202 for 3 units.
Same as: MATSCI 192

MATSCI 203. Atomic Arrangements in Solids. 3-4 Units.
Atomic arrangements in perfect and imperfect solids, especially important metals, ceramics, and semiconductors. Elements of formal crystallography, including development of point groups and space groups. Undergraduates register in 193 for 4 units; graduates register in 203 for 3 units.
Same as: MATSCI 193

MATSCI 204. Thermodynamics and Phase Equilibria. 3 Units.
The principles of heterogeneous equilibria and their application to phase diagrams. Thermodynamics of solutions; chemical reactions; non-stoichiometry in compounds; first order phase transitions and metastability; thermodynamics of surfaces, elastic solids, dielectrics, and magnetic solids. Offered online for grad students in summer quarter, while an in-person course for grads and undergrads will be available in winter quarter 2019.

MATSCI 205. Waves and Diffraction in Solids. 3-4 Units.
The elementary principals of x-ray, vibrational, and electron waves in solids. Basic wave behavior including Fourier analysis, interference, diffraction, and polarization. Examples of wave systems, including electromagnetic waves from Maxwell's equations. Diffraeted intensity in reciprocal space and experimental techniques such as electron and x-ray diffraction. Lattice vibrations in solids, including vibrational modes, dispersion relationship, density of states, and thermal properties. Free electron model. Basic quantum mechanics and statistical mechanics including Fermi-Dirac and Bose-Einstein statistics. Prerequisite: MATSCI 193/203 or consent of instructor. Undergraduates register for 195 for 4 units; graduates register for 205 for 3 units.
Same as: MATSCI 195, PHOTON 205

MATSCI 206. Defects in Crystalline Solids. 3-4 Units.
Thermodynamic and kinetic behaviors of 0-D (point), 1-D (line), and 2-D (interface and surface) defects in crystalline solids. Influences of these defects on the macroscopic ionic, electronic, and catalytic properties of materials, such as batteries, fuel cells, catalysts, and memory-storage devices. Prerequisite: MATSCI 193/203. Undergraduates register for 196 for 4 units; graduates register for 206 for 3 units.
Same as: MATSCI 196

MATSCI 207. Rate Processes in Materials. 3-4 Units.
Same as: MATSCI 197

MATSCI 208. Mechanical Properties of Materials. 3-4 Units.
Introduction to the mechanical behavior of solids, emphasizing the relationships between microstructure and mechanical properties. Elastic, anelastic, and plastic properties of materials. The relations between stress, strain, strain rate, and temperature for plastically deformable solids. Application of dislocation theory to strengthening mechanisms in crystalline solids. The phenomena of creep, fracture, and fatigue and their controlling mechanisms. Prerequisites: MATSCI 193/203.
Undergraduates register for 198 for 4 units; graduates register for 208 for 3 units.
Same as: MATSCI 198

MATSCI 209. Electronic and Optical Properties of Solids. 3-4 Units.
The concepts of electronic energy bands and transports applied to metals, semiconductors, and insulators. The behavior of electronic and optical devices including p-n junctions, MOS-capacitors, MOSFETs, optical waveguides, quantum-well lasers, light amplifiers, and metallo-dielectric light guides. Emphasis is on relationships between structure and physical properties. Elementary quantum and statistical mechanics concepts are used. Prerequisite: MATSCI 195/205 or equivalent.
Undergraduates register for 199 for 4 units; graduates register for 209 for 3 units.
Same as: MATSCI 199

MATSCI 210. Organic and Biological Materials. 3-4 Units.
Unique physical and chemical properties of organic materials and their uses. The relationship between structure and physical properties, and techniques to determine chemical structure and molecular ordering. Examples include liquid crystals, dendrimers, carbon nanotubes, hydrogels, and biopolymers such as lipids, protein, and DNA. Prerequisite: Thermodynamics and ENGR 50 or equivalent. Undergraduates register for 190 for 4 units; graduates register for 210 for 3 units.
Same as: MATSCI 190

MATSCI 230. Materials Science Colloquium. 1 Unit.
May be repeated for credit.

MATSCI 241. Mechanical Behavior of Nanomaterials. 3 Units.
Mechanical behavior of the following nanoscale solids: 2D materials (metal thin films, graphene), 1D materials (nanowires, carbon nanotubes), and 0D materials (metallic nanoparticles, quantum dots). This course will cover elasticity, plasticity and fracture in nanomaterials, defect-scarce nanomaterials; deformation near free surfaces, coupled optoelectronic and mechanical properties (e.g. piezoelectric nanowires, quantum dots), and nanomechanical measurement techniques. Prerequisites: Mechanics of Materials (ME80) or equivalent.
Same as: ME 241

MATSCI 250. Introduction to Materials Science, Biomaterials Emphasis. 3 Units.
Topics include: the relationship between atomic structure and macroscopic properties of man-made and natural materials; mechanical and thermodynamic behavior of surgical implants including alloys, ceramics, and polymers; and materials selection for biotechnology applications such as contact lenses, artificial joints, and cardiovascular stents. No prerequisite.
Same as: ONLINE ONLY

MATSCI 251. Microstructure and Mechanical Properties. 3-4 Units.
Primarily for students without a materials background. Mechanical properties and their dependence on microstructure in a range of engineering materials. Elementary deformation and fracture concepts, strengthening and toughening strategies in metals and ceramics. Topics: dislocation theory, mechanisms of hardening and toughening, fracture, fatigue, and high-temperature creep. Undergraduates register in 151 for 4 units; graduates register for 251 in 3 units.
Same as: MATSCI 151
**MATSCI 256. Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution. 3-4 Units.**
Operating principles and applications of emerging technological solutions to the energy demands of the world. The scale of global energy usage and requirements for possible solutions. Basic physics and chemistry of solar cells, fuel cells, and batteries. Performance issues, including economics, from the ideal device to the installed system. The promise of materials research for providing next generation solutions.

**MATSCI 299. Practical Training. 1 Unit.**
Educational opportunities in high-technology research and development labs in industry. Qualified graduate students engage in internship work and integrate that work into their academic program. Following the internship, students complete a research report outlining their work activity, problems investigated, key results, and any follow-on projects they expect to perform. Student is responsible for arranging own employment. See department student services manager before enrolling.

**MATSCI 300. Ph.D. Research. 1-15 Unit.**
Participation in a research project.

**MATSCI 301. Engineering Energy Policy Change. 2 Units.**
Public policy and economic decisions profoundly affect all aspects of the energy ecosystem, including its supply, distribution, storage and utilization. These decisions can also influence the pace and focus of innovation of new technologies, including through government-funded research and development programs or regulatory efforts. This course will equip graduate students, who have strong science and engineering backgrounds, with a basic ability to understand and shape the ideation and implementation of sound energy and, related economic, policy. Building on case studies of both aspirational and reactive U.S. energy policy-making, students will design their own policy proposals for new, ambitious and achievable moonshot goals that advance a sustainable and prosperous future. In particular, students will choose a moonshot goal designed to reduce U.S. (and/or global) transportation-related emissions. These proposals may focus on specific mobility technologies (e.g., new zero-GHG liquid fuels), lead to transformation of mobility systems (e.g., integration of wide-scale automation into the transportation sector), or reduce emissions in another way altogether (e.g., moving manufacturing closer to consumption through 3-d printing). Students will also be introduced to gunshot scenarios, moments of energy crisis that require robust response and can create openings for dramatic change to the energy ecosystem.

**MATSCI 302. Solar Cells. 3 Units.**
This course provides a comprehensive view of solar cells and what will need to be done to enable them to substantially change how the world obtains its electricity. After covering the fundamentals (light trapping, current flow in pn junctions, recombination) that are important for almost all photovoltaic technologies, the course will address technologies based on highly crystalline forms of silicon and gallium arsenide. The device simulator PC1D will be used to model solar cells. The course will then go through multijunctions cells with concentrators, low-cost thin-film solar cells, organic semiconductors, hybrid perovskites and nanowires. There will be discussions of module design and the economics of the solar industry. There will be a tour of a company that makes solar cells and guest lectures.

**MATSCI 303. Principles, Materials and Devices of Batteries. 3 Units.**
Thermodynamics and electrochemistry for batteries. Emphasis on lithium ion batteries, but also different types including lead acid, nickel metal hydride, metal air, sodium sulfur and redox flow. Battery electrode materials, electrolytes, separators, additives and electrode-electrolyte interface. Electrochemical techniques; advanced battery materials with nanotechnology; battery device structure. Prerequisites: undergraduate chemistry.

**MATSCI 311. Lasers in Materials Processing. 3 Units.**

**MATSCI 312. New Methods in Thin Film Synthesis. 3 Units.**
Materials base for engineering new classes of coatings and devices. Techniques to grow thin films at atomic scale and to fabricate multilayers/superlattices at nanoscale. Vacuum growth techniques including evaporation, molecular beam epitaxy (MBE), sputtering, ion beam assisted deposition, laser ablation, chemical vapor deposition (CVD), and electroplating. Future direction of material synthesis such as nanocluster deposition and nanoparticles self-assembly. Relationships between deposition parameters and film properties. Applications of thin film synthesis in microelectronics, nanotechnology, and biology. SCPD offering.

**MATSCI 316. Nanoscale Science, Engineering, and Technology. 3 Units.**
This course covers important aspects of nanotechnology in nanomaterials synthesis and fabrication, novel property at the nanoscale, tools and applications: a variety of nanostructures including nanocrystal, nanowire, carbon nanotube, graphene, nanoporous material, block copolymer, and self-assembled monolayer; nanofabrication techniques developed over the past 20 years; thermodynamic, electronic and optical property; applications in solar cells, batteries, biosensors and electronics. Other nanotechnology topics may be explored through a group project. SCPD offering.

**MATSCI 320. Nanocharacterization of Materials. 3 Units.**

**MATSCI 321. Transmission Electron Microscopy. 3 Units.**
Image formation and interpretation. The contrast phenomena associated with perfect and imperfect crystals from a physical point of view and from a formal treatment of electron diffraction theory. The importance of electron diffraction to systematic analysis and recent imaging developments. Recommended: 193/203, 195/205, or equivalent.

**MATSCI 322. Transmission Electron Microscopy Laboratory. 3 Units.**
Practical techniques in transmission electron microscopy (TEM): topics include microscope operation and alignment, diffraction modes and analysis, bright-field/dark-field imaging, high resolution and aberration corrected imaging, scanning TEM (STEM) imaging, x-ray energy dispersive spectrometry (EDS) and electron energy loss spectrometry (EELS) for compositional analysis and mapping. Prerequisite: 321, consent of instructor. Enrollment limited to 12.

**MATSCI 323. Thin Film and Interface Microanalysis. 3 Units.**
The science and technology of microanalytical techniques will be discussed. We consider ways to characterize the structural, compositional, morphological, electronic, optical, mechanical, and magnetic properties of surfaces and interfaces. We will talk about different types of surface analytical techniques that rely on the use of electrons, photons, ions, and sharp tips to learn about different aspects about surfaces. We also discuss strategies on how to combine such techniques to gain a more complete and quantitative picture of a surface. We will also describe the inner workings and design of the hardware involved in analyzing surfaces. Prerequisite: some prior exposure to atomic and electronic structure of solids.
MATSCI 326. X-Ray Science and Techniques. 3 Units.
This course provides an introduction to how x-rays interact with matter and how x-ray techniques can be used for developing new understanding of the properties of materials. Course topics include diffraction from ordered and disordered materials, x-ray absorption/ emission spectroscopy, photoemission, and coherent scattering. Sources including synchrotrons and x-ray lasers and an introduction to time-resolved techniques. This course includes a parallel laboratory effort in which students will have an opportunity to carry out experiments at the Stanford Synchrotron Radiation Lightsource at the SLAC National Accelerator Laboratory.
Same as: PHOTON 326

MATSCI 331. Atom-based computational methods for materials. 3 Units.

MATSCI 343. Organic Semiconductors for Electronics and Photonics. 3 Units.
The science of organic semiconductors and their use in electronic and photonic devices. Topics: methods for fabricating thin films and devices; relationship between chemical structure and molecular packing on properties such as band gap, charge carrier mobility and luminescence efficiency; doping; field-effect transistors; light-emitting diodes; lasers; biosensors; photodetectors and photovoltaic cells.

MATSCI 346. Nanophotonics. 3 Units.
Same as: EE 336

MATSCI 347. Magnetic materials in nanotechnology, sensing, and energy. 3 Units.
This course will teach the fundamentals of magnetism, magnetic materials, and magnetic nanostructures and their myriad of applications in nanotechnology, sensing, energy and related areas. The scope of the course include: atomic origins of magnetic moments, magnetic exchange and ferromagnetism, types of magnetic order, magnetic anisotropy, domains, domain walls, hysteresis loops, hard and soft magnetic materials, demagnetization factors, magnetic nanoparticles and nanostructures, spintronics, and multiferroics. The key applications include electromagnet and permanent magnet, magnetic inductors, magnetic sensors, magnetic memory, hard disk drives, energy generation and harvesting, biomagnetism, etc. Prerequisites: College level electricity and magnetism course or equivalent.

MATSCI 353. Mechanical Properties of Thin Films. 3 Units.
The mechanical properties of thin films on substrates. The mechanics of thin films and of the atomic processes which cause stresses to develop during thin film growth. Experimental techniques for studying stresses in and mechanical properties of thin films. Elastic, plastic, and diffusional deformation of thin films on substrates as a function of temperature and microstructure. Effects of deformation and fracture on the processing of thin film materials. Prerequisite: 198/208.

MATSCI 358. Fracture and Fatigue of Materials and Thin Film Structures. 3 Units.
Linear-elastic and elastic-plastic fracture mechanics from a materials science perspective, emphasizing microstructure and the micromechanisms of fracture. Plane strain fracture toughness and resistance curve behavior. Mechanisms of failure associated with cohesion and adhesion in bulk materials, composites, and thin film structures. Fracture mechanics approaches to toughening and subcritical crack-growth processes, with examples and applications involving cyclic fatigue and environmentally assisted subcritical crack growth. Prerequisite: 151/251, 198/208, or equivalent. SCPD offering.

MATSCI 359. Crystalline Anisotropy. 3 Units.
Matrix and tensor analysis with applications to the effects of crystal symmetry on elastic deformation, thermal expansion, diffusion, piezoelectricity, magnetism, thermodynamics, and optical properties of solids, on the level of J. F. Nye's Physical Properties of Crystals. Homework sets use Mathematica.

MATSCI 380. Nano-Biotechnology. 3 Units.

MATSCI 381. Biomaterials in Regenerative Medicine. 3 Units.
Materials design and engineering for regenerative medicine. How materials interact with cells through their micro- and nanostructure, mechanical properties, degradation characteristics, surface chemistry, and biochemistry. Examples include novel materials for drug and gene delivery, materials for stem cell proliferation and differentiation, and tissue engineering scaffolds. Prerequisites: undergraduate chemistry, and cell/molecular biology or biochemistry.
Same as: BIOE 361

MATSCI 382. Biochips and Medical Imaging. 3 Units.
The course covers state-of-the-art and emerging bio-sensors, bio-chips, imaging modalities, and nano-therapies which will be studied in the context of human physiology including the nervous system, circulatory system and immune system. Medical diagnostics will be divided into bio-chips (in-vitro diagnostics) and medical and molecular imaging (in-vivo imaging). In-depth discussion on cancer and cardiovascular diseases and the role of diagnostics and nano-therapies.
Same as: EE 225, S BIO 225
MATSCI 384. Materials Advances in Neurotechnology: Materials Meeting the Mind. 3 Units.
The dichotomy between the material world and the mental world has driven the curiosity of scientists to explore the wonders of the brain, as well as motivated the continued innovations of novel technologies based on advances in materials science and engineering to understand the brain. This course introduces the basic principles of materials design and fabrication for probing the inner workings of the brain, discusses the fundamental challenges of state-of-the-art neurotechnologies, and explores the latest breakthroughs in materials-assisted neuroengineering. The course will cover the following topics: fundamentals of electrophysiology of the nervous system, mechanical and biochemical requirements of neural interfacing materials, materials for electrical neural interfaces (tungsten/carbon electrodes, Utah/Michigan/ECoG electrode arrays), materials for optical neural interfaces (optical fibers/waveguides for optogenetics, micropriisms/GIRN lenses for fluorescence imaging of neural activity), and materials for biochemical neural interfaces (implantable microfluidic probes, neurotrophic scaffolds). Students will be able to speak the languages of both materials science and neuroengineering and acquire the knowledge and skills to understand and address pressing neuroscience challenges with materials advances. This course will include lectures, student discussions/presentations and guest lectures given by pioneers in related fields at Stanford and other schools/companies in the local area. Prerequisite: undergraduate physics and chemistry; MATSCI 152, 158, 164, 190 or equivalents are recommended but not required prior to taking this course.

MATSCI 399. Graduate Independent Study. 1-10 Unit.
Under supervision of a faculty member.

MATSCI 400. Participation in Materials Science Teaching. 1-3 Unit.
May be repeated for credit.

MATSCI 801. TGR Project for MS Students. 0 Units.

MATSCI 802. TGR Dissertation for Ph.D Students. 0 Units.

MATSCI 81N. Bioengineering Materials to Heal the Body. 3 Units.
Preference to freshmen. Real-world examples of materials developed for tissue engineering and regenerative medicine therapies. How scientists and engineers design new materials for surgeons to use in replacing body parts such as damaged heart or spinal cord tissue. How cells interact with implanted materials. Students identify a clinically important disease or injury that requires a better material, proposed research approaches to the problem, and debate possible engineering solutions.

MATSCI 82N. Science of the Impossible. 3 Units.
Imagine a world where cancer is cured with light, objects can be made invisible, and teleportation is allowed through space and time. The future once envisioned by science fiction writers is now becoming a reality, thanks to advances in materials science and engineering. This seminar will explore "impossible" technologies - those that have shaped our past and those that promise to revolutionize the future. Attention will be given to both the science and the societal impact of these technologies. We will begin by investigating breakthroughs from the 20th century that seemed impossible in the early 1900s, such as the invention of integrated circuits and the discovery of chemotherapy. We will then discuss the scientific breakthroughs that enabled modern "impossible" science, such as photodynamic cancer therapeutics, invisibility, and psychokinesis through advanced mind-machine interfaces. Lastly, we will explore technologies currently perceived as completely impossible and brainstorm the breakthroughs needed to make such science fiction a reality. The course will include introductory lectures and in-depth conversations based on readings. Students will also be given the opportunity to lead class discussions on a relevant "impossible science" topic of their choosing.

MATSCI 83N. Great Inventions That Matter. 3 Units.
This introductory seminar starts by illuminating on the general aspects of creativity, invention, and patenting in engineering and medicine, and how Stanford University is one of the world’s foremost engines of innovation. We then take a deep dive into some great technological inventions which are still playing an essential role in our everyday lives, such as fiber amplifier, digital compass, computer memory, HIV detector, personal genome machine, cancer cell sorting, brain imaging, and mind reading. The stories and underlying materials and technologies behind each invention, including a few examples by Stanford faculty and student inventors, are highlighted and discussed. A special lecture focuses on the public policy on intellectual properties (IP) and the resources at Stanford Office of Technology Licensing (OTL). Each student will have an opportunity to present on a great invention from Stanford (or elsewhere), or to write a (mock) patent disclosure of his/her own ideas.

MATSCI 85N. Health Fab: Making Stuff for Life. 3 Units.
Semiconductor-based chip technology is all around us; in our phones, computers, and cars. However, not all capabilities developed for silicon processing are directed towards computers and mobile devices. A new field has emerged using these fabrication and patterning techniques for medical devices, health monitoring, and human-machine interfaces. We can now create chips that flow not electrons, but liquids, taking samples and performing analyses. These liquid based functions can be integrated together with silicon electronic devices for sensing, control, or manipulation. FitBits and Apple Watches are examples of the first generation of "wearable" electronics, while more advanced devices that incorporate both liquid based sensors and electronics are on their way. In this class, we will learn some fundamentals of device fabrication for biomedical purposes, take you inside the Stanford NanoFabrication Facility (SNF), and create microfluidic devices. We will cover what is possible with current microfabrication techniques, including direct-write lithography, laser cutting, three-dimensional two photon patterning, polymer deposition and metal patterning. Students will learn how to design, fabricate, and test microfluidic and biomedically related devices. In addition to teaching and hands-on training in microfluidic fabrication, the class will include four team-based projects, each with a different device goal. These projects requirements will be submitted by leading research groups at Stanford, providing up-to-date and real world challenges. Each team will work together to identify specific device needs, invent solutions, and built prototype devices. At the end of the course each team will present its designs to the sponsoring research program and describe how they met the required objectives. No prior experience with device fabrication is needed.