SCHOOL OF ENGINEERING

MATERIALS SCIENCE AND ENGINEERING

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Courses offered by the Department of Materials Science and Engineering are listed under the subject code MATSCI on the *Stanford Bulletin's* ExploreCourses web site.

The Department of Materials Science and Engineering is concerned with the relation between the structure and properties of materials, factors that control the internal structure of solids, and processes for altering their structure and properties, particularly at the nano-scale. The undergraduate program, described under the "School of Engineering" section of this bulletin, provides training for the materials engineer and also preparatory training for graduate work in materials science. Capable students are encouraged to take at least one year of graduate study to extend their course work to obtain a coterminal degree. Coterminal degree programs are encouraged both for undergraduate majors in Materials Science and Engineering and for undergraduate majors in related disciplines. Graduate programs lead to the degrees of Master of Science, Engineer, and Doctor of Philosophy.

FACILITIES

The department is based in the William F. Durand Building, with extensive facilities in the Jack A. McCullough building and the Gordon and Betty Moore Materials Research Building. These buildings house offices for the chair and most of the faculty, for the administrative and technical staff, and for most graduate students, along with lecture and seminar rooms. Facilities for teaching and research are also available, including equipment for electrical measurements; mechanical testing of bulk and thin film materials; fracture and fatigue of advanced materials; metallography; optical, scanning, transmission electron microscopy, and atomic force microscopy; UHV sputter deposition; vacuum annealing treatments; wet chemistry; and x-ray diffraction. The McCullough/Moore Complex is also the home for the Center for Magnetic Nanotechnology, with corresponding facilities for magnetic measurements, and to the Stanford Nanocharacterization Laboratory (SNL). The Rapid Prototyping Laboratory (RPL), housing material deposition and removal stations, is a joint facility with Mechanical Engineering, and is housed in Building 530. The department maintains a microcomputer cluster for its students, which is linked to the internet.

Depending on the needs of their programs, students and faculty also conduct research in a number of other departments and independent laboratories. Chief among these are the Stanford Nanofabrication Facility (SNF), the Geballe Laboratory for Advanced Materials (GLAM), and the Stanford Synchrotron Radiation Laboratory (SSRL).

The Stanford Nanofabrication Facility (SNF) is a laboratory joining government and industrially funded research on microelectronic materials, devices, and systems. It houses a 10,000 square foot, class 100 clean room for Si and GaAs integrated circuit fabrication; a large number of electronic test, materials analysis, and computer facilities; and office space for faculty, staff, and students. In addition, the Center for Integrated Systems (CIS) provides startup research funds and maintains a Fellow-Mentor program with industry.

For information on GLAM and SSRL, see the "Geballe Laboratory for Advanced Materials" and "Stanford Synchrotron Radiation Laboratory" sections of this bulletin.

BACHELOR OF SCIENCE IN MATERIALS SCIENCE AND ENGINEERING

MISSION STATEMENT

The mission of the Materials Science and Engineering Program is to provide students with a strong foundation in materials science and engineering. The program's curriculum places special emphasis on the fundamental scientific and engineering principles which underlie the knowledge and implementation of materials structure, processing, properties, and performance of all classes of materials used in engineering systems. Courses in the program develop students' knowledge of modern materials science and engineering and teach them to apply this knowledge analytically to create effective and novel solutions to practical problems. The program prepares students for careers in industry or for further study in graduate school.

The undergraduate program provides training in solid state fundamentals and materials engineering. Students desiring to specialize in this field during their undergraduate period may do so by following the curriculum outlined in the "School of Engineering" section of this bulletin as well as the *School of Engineering Undergraduate Handbook*. The University's basic requirements for the bachelor's degree are discussed in the "Undergraduate Degrees and Programs" section of this bulletin. Electives are available so that students with broad interests can combine materials science and engineering with work in another science or engineering department.

For information about the minor, see the "School of Engineering" section of this bulletin.

GRADUATE PROGRAMS IN MATERIALS SCIENCE ENGINEERING

Graduate students can specialize in any of the areas of materials science and engineering.

COTERMINAL B.S./M.S. PROGRAM IN MATERIALS SCIENCE ENGINEERING

Stanford undergraduates who wish to continue their studies for the Master of Science degree in the coterminal program may apply for admission after they have earned 120 units toward graduation (UTG) as shown on the undergraduate unofficial transcript; applicants must submit their application no later than the quarter prior to the quarter of the expected completion of their undergraduate degree. The application must give evidence that the student possesses the potential for strong academic performance at the graduate level. Scores from the Graduate Record Exam (GRE) General Test must be reported before action can be taken on an application. Materials science is a highly integrated and interdisciplinary subject, and so applications from students of any engineering or science undergraduate major are encouraged. Information forms pertaining to the coterminal program may be obtained from the department's student services office in Durand 115.

For University coterminal degree program rules and University application forms, see http://registrar.stanford.edu/shared/ publications.htm#Coterm.

MASTER OF SCIENCE IN MATERIALS SCIENCE ENGINEERING

The University's basic requirements for the M.S. degree are discussed in the "Graduate Degrees" section of this bulletin. The following are specific departmental requirements.

The Department of Materials Science and Engineering requires a minimum of 45 units for a master's degree to be taken in residence at Stanford. Master's Program Proposal forms should be filled out, signed by the student's academic adviser, and submitted to the department's student services manager by the end of the student's first quarter of study. Final changes to the master's program must be submitted no later than one academic quarter prior to the quarter of expected degree conferral. Stanford Materials Science undergraduates who are pursuing or who plan to pursue a coterminal M.S. degree may have more flexibility in their programs and should consult with their academic advisers regarding appropriate core course and elective choices.

Degree requirements are as follows:

1. A minimum of 30 units of Materials Science course work, including core and lab courses specified below, taken for a letter grade. Research units, one-unit seminars, and courses in other departments (i.e., where students cannot enroll in a class with a MATSCI subject code) cannot be counted for this requirement.
2. Three core courses: 203; 204; 207.
3. Lab courses: MATSCI 171, 172, 173. *Note:* students who have had equivalent lab courses at other universities, equivalent practical experience, a materials related degree or background, or passed the Ph.D. qualifying exam, are expected to file a petition with the department's student services manager to have this requirement waived and to substitute other appropriate technical courses for the lab units.
4. 15 units of approved course electives that result in a technically coherent program. Of the 15 units of elective courses:
   a. 12 of the 15 units must be taken for a letter grade (except for those submitting an M.S. report).
   b. a maximum of three units may be seminars.
   c. if writing a master's research report, a minimum of six and a maximum of 15 units of Materials Science research units (MATSCI 200) may be counted. M.S. research units may only be counted if writing an M.S. research report. See student services manager for approval.
   d. a maximum of three units may be undergraduate units (offered at Stanford University).
   e. a maximum of five units may be used for a foreign language course (not including any remedial English courses or courses in the student's native language if other than English).
   f. the combination of seminar, undergraduate, and language units may not exceed six units total.
   g. the combination of research, seminar, undergraduate, and language units may not exceed 15 units total.
   h. activity units may not be counted toward a graduate degree.
5. A minimum grade point average (GPA) of 2.75 for degree course work taken at Stanford.

All proposed degree programs are subject to approval by the department's student services manager and the Academic Degree Committee, which has responsibility for assuring that each proposal is a technically coherent program.

MASTER'S RESEARCH REPORT

Students wishing to take this option must include 6-15 Materials Science research units on their program proposal and the name of the faculty member supervising the research. Students using 15 units of research toward the degree must participate in a more complex and demanding research project than those using fewer units.

The report must be approved by two faculty members. One faculty member is the student's research adviser. The other faculty member must be approved by the department's student services manager. Three copies of the report (one copy for each approving faculty member and one for the department file), in final form and signed by the two faculty members, must be submitted to the department's student services manager one week before final examinations of the final quarter of the program. The report is not an official University thesis but rather is intended to demonstrate to department faculty an ability to conduct and report directed research. Refer to the *Materials Science and Engineering Student Handbook* for further clarification concerning this report.

In cases where students decide to pursue research after the initial program submission deadline, they should submit a revised M.S. Program Proposal at least two quarters before the degree is granted. The total combined units of Materials Science research units, seminars, language courses, and undergraduate courses cannot exceed 15. If a master's research report is not to be submitted, units of MATSCI 200 cannot be applied to the department's requirement of 45 units for the master's degree.

HONORS COOPERATIVE PROGRAM

Some of the department's graduate students participate in the Honors Cooperative Program (HCP), which makes it possible for academically qualified engineers and scientists in industry to be part-time graduate students in Materials Science while continuing professional employment. Prospective HCP students follow the same admissions process and must meet the same admissions requirements as full-time graduate students. For information regarding the Honors Cooperative Program, see the "School of Engineering" section of this bulletin.

PETITION PROCESS FOR TRANSFER FROM M.S. TO PH.D. DEGREE PROGRAM

Students admitted to the graduate program are admitted specifically into either the M.S. or the Ph.D. program. A student admitted to the M.S. program should not assume admission to the Ph.D. program. Admission to the Ph.D. program is required for the student to be eligible to work towards the Ph.D. degree.

A student in the M.S. program may petition to be admitted to the Ph.D. program by filing an M.S. to Ph.D. Transfer Petition. This petition must be accompanied by a one-page statement of purpose stating the reasons why the student wishes to transfer to the Ph.D. program, an updated transcript, and two letters of recommendation from members of the Stanford faculty, including one from the student's prospective adviser and at least one from a Materials Science faculty member belonging to the Academic Council. The M.S. to Ph.D. Transfer Petition is due to the student services manager by the end of the second week of Spring Quarter during the student's first year in the M.S. program. Only students enrolled in the 200 series core course sequence are eligible to petition, and a grade point average (GPA) of 3.5 or better in the core courses is required.

Transferring to the Ph.D. program is a competitive process and only fully qualified M.S. students are admitted. Faculty consider the student's original application to the graduate program as well as the material provided with the transfer petition.

ENGINEER IN MATERIALS SCIENCE ENGINEERING

The University's basic requirements for the degree of Engineer are outlined in the "Graduate Degrees" section of this bulletin.

A student wishing to enter the Engineer program must have completed the requirements of the M.S. in Materials Science and Engineering, and must file a petition requesting admission to the program, stating the type of research to be done and the proposed supervising professor. Once approved, the Application for Candidacy must be submitted to the department's student services manager by the end of the second quarter in the Engineer program. Final changes in the Application for Candidacy form must be submitted no later than one academic quarter prior to degree conferral.

The 90-unit program must include 9 units of graduate courses in Materials Science with a MATSCI subject code (exclusive of research units, seminars, colloquia, and MATSCI 400, Participation in Teaching) beyond the requirements for the M.S. degree, and additional research or other units to meet the 90-unit University minimum requirement. A grade point average (GPA) of 3.0 must be maintained for all degree course work taken at Stanford.

Completion of an acceptable thesis is required. The Engineer thesis must be approved by two Academic Council faculty members, one of whom must be a member of the department, and submitted in triplicate.

DOCTOR OF PHILOSOPHY IN MATERIALS SCIENCE ENGINEERING

The University's basic requirements for the Ph.D. degree are outlined in the "Graduate Degrees" section of this bulletin.

Degree requirements for the department are as follows:

1. Students must submit a Ph.D. program plan consisting of at least 135 units,* which contains a minimum of 48 core, approved technical and seminar units.† For these 48 units:
   a. 30 units Materials Science and Engineering required core courses (MATSCI 201**, 202, 203, 204, 205, 206, 207, 208, 209, 210) must be taken, with at least six core courses (including MATSCI 203, 204, 207) during the first year
   b. 15 elective graduate technical units directly relevant to Materials Science and Engineering must be taken (units not to include MATSCI 300, Ph.D Research, MATSCI 400, Participation in Materials Science Teaching, or MATSCI 299, Practical Training)
   c. all core and technical classes must be for a letter grade
   d. first-year Ph.D. students are required to take the Materials Science Colloquium, MATSCI 230 (1 unit), each quarter of their first year (not counted as technical course units). Note that attendance is required, roll is taken, and that more than two absences results in an automatic 'NP' grade.
2. The remaining 87 units are to be at least 75 units of MATSCI 300, Ph.D. research, and up to 12 units of other courses (may include MATSCI 400, Participation in Materials Science Teaching, and a maximum 3 units of MATSCI 299, Practical Training).
3. Students must consult with their Academic Adviser on program planning. The program planning sheet must be submitted with the approval of the student's Dissertation Adviser on joining that research group, and no later than the end of spring quarter of the the first year. For students with a non-MATSCI Dissertation Adviser, the MATSCI Academic Adviser must also approve the list of proposed courses. Any proposed deviations from the requirements can only be considered by petition.
4. Ph.D. students are required to obtain an M.S. degree in Materials Science normally by the end of their second year. A Graduate Program Authorization Petition and a M.S. Program Proposal must be submitted prior to taking the qualifying examination. Courses taken for the 48 core and technical units of Ph.D. work may count towards the M.S. degree requirements.
5. A departmental oral qualifying examination must be passed by the end of January of the second year. A grade point average (GPA) of 3.5 from the six core classes taken is required for admission to the Ph.D. qualifying exam. Students who have passed the Ph.D. Qualifying exam are required to complete the Application for Candidacy for the Ph.D. degree by the end of the quarter in which they pass the exam. Final changes in the Application for Candidacy form must be submitted no later than one academic quarter prior to degree conferral.
6. Maintain a GPA of 3.0 in all degree courses taken at Stanford.
7. Students must present the results of the dissertation at the University Ph.D. oral examination.
8. Current students subject to either this set of requirements or a prior set must obtain the approval of their adviser before filing a revised program sheet, and should as far as possible adhere to the intent of the new requirements.
9. Students may reference the list of Advanced Speciality Courses and Cognate Courses provided below as guidance for their selection of technical units. As noted above, Academic Adviser approval is required.

* At least 90 units must be taken in residence at Stanford. Students entering with an M.S. degree in Materials Science from another university may request to transfer up to 45 units of equivalent work toward the total of 135 required units.

† Students may, if they have sufficient background, petition out of some of the required core courses. To petition, students must have prior consent from their academic adviser, and consent from the instructor of the core course. That instructor provides an oral or written examination that the petitioning student must pass.

** To be offered 2010-11.

ADVANCED SPECIALTY COURSES

Biomaterials: APPPHYS 292; BIOPHYS 228; CHEMENG 260, 310, 355; ME 284A,B, 381, 385, 457; MATSCI 380, 381

Electronic Materials Processing: EE 212, 216, 311, 316, 410; MATSCI 312

Materials Characterization: APPPHYS 216, CHEMENG 345; EE 329; MATSCI 320, 321, 322, 323, 325, 326

Mechanical Behavior of Solids: AA 252, 256; MATSCI 251, 353, 358; ME 335A,B,C, 340, 340A,B, 345

Physics of Solids and Computation: APPPHYS 272, 273; EE 222, 223, 228, 327, 328, 329, 335; MATSCI 343, 347; ME 344A,B

Soft Materials: CHEMENG 260, 310, 460; MATSCI 343; ME 455

COGNATE COURSES

AA 252. Techniques of Failure Analysis
AA 256. Mechanics of Composites
APPPHYS 216. X-Ray and VUV Physics
APPPHYS 270. Magnetism and Long Range Order in Solids
APPPHYS 272,273. Solid State Physics I,II
APPPHYS 292. Introductory Biophysics
BIOPHYS 228. Computational Structural Biology
CHEMENG 260. Polymer Science and Engineering
CHEMENG 310. Microhydrodynamics
CHEMENG 345. Fundamentals and Applications of Spectroscopy
CHEMENG 355. Advanced Biochemical Engineering
CHEMENG 460. Polymer Surfaces and Interfaces
EE 212. Integrated Circuit Fabrication Processes
EE 216. Principles and Models of Semiconductor Devices
EE 217. Electron and Ion Beams for Semiconductor Processing
EE 222,223. Applied Quantum Mechanics I,II
EE 228. Basic Physics for Solid State Electronics
EE 311. Advanced Integrated Circuit Fabrication Processes
EE 312. Micromachined Sensors and Actuators
EE 316. Advanced VLSI Devices
EE 327. Properties of Semiconductor Materials
EE 328. Physics of Advanced Semiconductor Devices
EE 329. The Electronic Structure of Surfaces and Interfaces
EE 335. Introduction to Information Storage Systems

EE 410. Integrated Circuit Fabrication Laboratory
ENGR 31. Chemical Principles with Application to Nanoscale Science and Technology
ENGR 50. Introduction to Materials Science, Nanotechnology Emphasis
ENGR 50M. Introduction to Materials Science, Biomaterials Emphasis
ME 284A,B. Cardiovascular Bioengineering
ME 329. Physical Solid Mechanics
ME 335A,B. Finite Element Analysis
ME 335C. Introduction to Boundary Element Analysis
ME 340A. Theory and Applications of Elasticity
ME 340B. Elasticity in Microscopic Structures
ME 344A. Computational Nanotechnology
ME 344B. Nanomaterials Modeling
ME 345. Fatigue Design and Analysis
ME 381. Orthopaedic Bioengineering
ME 385. Tissue Engineering Lab
ME 455. Complex Fluids and Non-Newtonian Flows
ME 457. Fluid Flow in Microdevices
PHYSICS 230,231. Quantum Mechanics

PH.D. MINOR IN MATERIALS SCIENCE AND ENGINEERING

The University's basic requirements for the Ph.D. minor are outlined in the "Graduate Degrees" section of this bulletin. A minor requires 20 units of graduate work of quality and depth to be approved by the advanced degree committee of the department. Individual programs must be submitted to the student services manager at least one quarter prior to degree conferral and approved as are other academic plans.

MATERIALS SCIENCE AND ENGINEERING (MATSCI)

UNDERGRADUATE COURSES IN MATERIALS SCIENCE AND ENGINEERING

ATSCI 70N. Building the Future: Invention and Innovation with Engineering Materials
(F,Sem) Stanford Introductory Seminar. Preference to freshmen. The technological importance of materials in human civilization is captured in historical names such as the Stone, Bronze, and Iron Ages. The present Information Age could rightly be called the Silicon Age. The pivotal roles of materials in the development of new technologies. Quantitative problem sets, field trips, and formal presentations of small-group projects. GER:DB-EngrAppSci
5 units, Spr (Bravman, J)

MATSCI 100. Undergraduate Independent Study
Independent study in materials science under supervision of a faculty member.
1-3 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

MATSCI 150. Undergraduate Research
Participation in a research project.
3-6 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

MATSCI 151. Microstructure and Mechanical Properties
(Same as MATSCI 251) 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. Prerequisite: ENGR 50 or equivalent. GER:DB-EngrAppSci
3-4 units, Aut (Dauskardt, R)

MATSCI 152. Electronic Materials Engineering
Materials science and engineering for electronic device applications. Kinetic molecular theory and thermally activated processes; band structure and electrical conductivity of metals and semiconductors; intrinsic and extrinsic semiconductors; diffusion; elementary p-n junction theory; operating principles of metal-oxide-semiconductor field effect transistors. Semiconductor processing including crystal growth, oxidation kinetics, ion implantation, thin film deposition, etching, and photolithography. Prerequisite: ENGR 50 or equivalent. GER:DB-EngrAppSci
4 units, Spr (Staff)

MATSCI 153. Nanostructure and Characterization
The structure of materials at the nanoscale is in most cases the same crystalline form as the natural phase. Structures of materials such as semiconductors, ceramics, metals, and nanotubes; classification of these materials according to the principles of crystallography. Primary methods of structural characterization, X-ray diffraction, and electron microscopy; their applications to study such nanostructures. GER:DB-EngrAppSci
4 units, Win (Sinclair, R)

MATSCI 154. Solid State Thermodynamics
The principles of thermodynamics and relationships between thermodynamic variables. Equilibrium in thermodynamic systems. Thermodynamics of multicomponent systems. GER:DB-EngrAppSci
4 units, Aut (Barnett, D)

MATSCI 155. Nanomaterials Synthesis
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. GER:DB-EngrAppSci
4 units, Spr (Clemens, B)

MATSCI 156. Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution
(Same as MATSCI 256) 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. GER:DB-EngrAppSci
3-4 units, Aut (Clemens, B)

MATSCI 157. Quantum Mechanics of Nanoscale Materials
Introduction to quantum mechanics and its application to the properties of materials. The Schrödinger equation, uncertainty principle, bound states and periodic potentials, angular momentum, quantum statistics, and perturbation theory. Applications to electronic band structure in semiconductors, metals, and nanostructures; vibrational properties of solids; light/matter interaction and lasers; bonding; magnetic materials; nanotechnology. Prerequisites: working knowledge of calculus and high school physics. GER:DB-EngrAppSci
4 units, Win (Lindenberg, A)

MATSCI 159Q. Japanese Companies and Japanese Society
(S,Sem) (Same as ENGR 159Q) Stanford Introductory Seminar. 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. GER:DB-SocSci
3 units, Spr (Sinclair, R)

MATSCI 160. Nanomaterials Laboratory
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. GER:DB-EngrAppSci
4 units, Spr (Melosh, N)

MATSCI 161. Nanocharacterization Laboratory
(Same as MATSCI 171) The development of standard lab procedures for materials scientists emphasizing microscopy, metallography, and technical writing. Techniques: optical, scanning-electron, atomic-force microscopy; and metallographic specimen preparation. The relationships among microscopic observation, material properties, and processing. Prerequisite: ENGR 50 or equivalent. GER:DB-EngrAppSci, WIM
3-4 units, Spr (McGehee, M)

MATSCI 162. X-Ray Diffraction Laboratory
(Same as MATSCI 172) 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 amorphorous 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. GER:DB-EngrAppSci
3-4 units, Win (Vailionis, A)

MATSCI 163. Mechanical Behavior Laboratory
(Same as MATSCI 173) 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. Prerequisite: ENGR 50. GER:DB-EngrAppSci
3-4 units, Aut (Han, S)

MATSCI 164. Electronic and Photonic Materials and Devices Laboratory
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: 152 or 199 or consent of instructor. GER:DB-EngrAppSci, WIM
4 units, Aut (Salleo, A)

MATSCI 190. Organic and Biological Materials
(Same as MATSCI 210) 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. GER:DB-EngrAppSci
3-4 units, Spr (Heilshorn, S)

MATSCI 192. Materials Chemistry
(Same as MATSCI 202) Chemical principles of materials: atomic and molecular bonding; acid and base chemistry; redox and electrochemistry; colloidal and surface chemistry; materials synthesis; and nanoscale chemistry. GER:DB-EngrAppSci
3-4 units, Aut (Cui, Y)

MATSCI 193. Atomic Arrangements in Solids
(Same as MATSCI 203) 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. GER:DB-EngrAppSci
3-4 units, Aut (Sinclair, R)

MATSCI 194. Thermodynamics and Phase Equilibria
(Same as MATSCI 204) 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. GER:DB-EngrAppSci
3-4 units, Win (Salleo, A)

MATSCI 195. Waves and Diffraction in Solids
(Same as MATSCI 205) 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. Diffracted 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: 193/203 or consent of instructor. GER:DB-EngrAppSci
3-4 units, Win (Clemens, B)

MATSCI 196. Imperfections in Crystalline Solids
(Same as MATSCI 206) The relation of lattice defects to the physical and mechanical properties of crystalline solids. Introduction to point imperfections and their relationship to transport properties in metallic, covalent, and ionic crystals. Geometric, crystallographic, elastic, and energetic properties of dislocations. Relations between dislocations and the mechanical properties of crystals. The structure and properties of interfaces in solids. Prerequisite: 193/203. GER:DB-EngrAppSci
3-4 units, Spr (Staff)

MATSCI 197. Rate Processes in Materials
(Same as MATSCI 207) Diffusion and phase transformations in solids. Diffusion topics: Fick's laws, atomic theory of diffusion, and diffusion in alloys. Phase transformation topics: nucleation, growth, diffusional transformations, spinodal decomposition, and interface phenomena. Material builds on the mathematical, thermodynamic, and statistical mechanical foundations in the prerequisites. Prerequisites: 194/204. GER:DB-EngrAppSci
3-4 units, Spr (McIntyre, P)

MATSCI 198. Mechanical Properties of Materials
(Same as MATSCI 208) 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: 193/203. GER:DB-EngrAppSci
3-4 units, Win (Dauskardt, R)

MATSCI 199. Electronic and Optical Properties of Solids
(Same as MATSCI 209) 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: 195/205 or equivalent. GER:DB-EngrAppSci
3-4 units, Spr (Brongersma, M)

GRADUATE COURSES IN MATERIALS SCIENCE AND ENGINEERING

MATSCI 171. Nanocharacterization Laboratory
(Same as MATSCI 161) The development of standard lab procedures for materials scientists emphasizing microscopy, metallography, and technical writing. Techniques: optical, scanning-electron, atomic-force microscopy; and metallographic specimen preparation. The relationships among microscopic observation, material properties, and processing. Prerequisite: ENGR 50 or equivalent.
3-4 units, Spr (McGehee, M)

MATSCI 172. X-Ray Diffraction Laboratory
(Same as MATSCI 162) 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 amorphorous 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.
3-4 units, Win (Vailionis, A)

MATSCI 173. Mechanical Behavior Laboratory
(Same as MATSCI 163) 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. Prerequisite: ENGR 50.
3-4 units, Aut (Han, S)

MATSCI 200. Master's Research
Participation in a research project.
1-15 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

MATSCI 202. Materials Chemistry
(Same as MATSCI 192) Chemical principles of materials: atomic and molecular bonding; acid and base chemistry; redox and electrochemistry; colloidal and surface chemistry; materials synthesis; and nanoscale chemistry.
3-4 units, Aut (Cui, Y)

MATSCI 203. Atomic Arrangements in Solids
(Same as MATSCI 193) 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.
3-4 units, Aut (Sinclair, R)

MATSCI 204. Thermodynamics and Phase Equilibria
(Same as MATSCI 194) 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.
3-4 units, Win (Salleo, A)

MATSCI 205. Waves and Diffraction in Solids
(Same as MATSCI 195) 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. Diffracted 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: 193/203 or consent of instructor.
3-4 units, Win (Clemens, B)

MATSCI 206. Imperfections in Crystalline Solids
(Same as MATSCI 196) The relation of lattice defects to the physical and mechanical properties of crystalline solids. Introduction to point imperfections and their relationship to transport properties in metallic, covalent, and ionic crystals. Geometric, crystallographic, elastic, and energetic properties of dislocations. Relations between dislocations and the mechanical properties of crystals. The structure and properties of interfaces in solids. Prerequisite: 193/203.
3-4 units, Spr (Staff)

MATSCI 207. Rate Processes in Materials
(Same as MATSCI 197) Diffusion and phase transformations in solids. Diffusion topics: Fick's laws, atomic theory of diffusion, and diffusion in alloys. Phase transformation topics: nucleation, growth, diffusional transformations, spinodal decomposition, and interface phenomena. Material builds on the mathematical, thermodynamic, and statistical mechanical foundations in the prerequisites. Prerequisites: 194/204.
3-4 units, Spr (McIntyre, P)

MATSCI 208. Mechanical Properties of Materials
(Same as MATSCI 198) 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: 193/203.
3-4 units, Win (Dauskardt, R)

MATSCI 209. Electronic and Optical Properties of Solids
(Same as MATSCI 199) 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: 195/205 or equivalent.
3-4 units, Spr (Brongersma, M)

MATSCI 210. Organic and Biological Materials
(Same as MATSCI 190) 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.
3-4 units, Spr (Heilshorn, S)

MATSCI 230. Materials Science Colloquium
May be repeated for credit.
1 unit, Aut (Brongersma, M; Cui, Y), Win (Sinclair, R; Salleo, A), Spr (Dauskardt, R; Heilshorn, S)

MATSCI 251. Microstructure and Mechanical Properties
(Same as MATSCI 151) 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. Prerequisite: ENGR 50 or equivalent.
3-4 units, Aut (Dauskardt, R)

MATSCI 256. Solar Cells, Fuel Cells, and Batteries: Materials for the Energy Solution
(Same as MATSCI 156) 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.
3-4 units, Aut (Clemens, B)

MATSCI 299. Practical Training
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.
3 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

MATSCI 300. Ph.D. Research
Participation in a research project.
1-15 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

MATSCI 302. Solar Cells
Theory of conventional p-n junction and excitonic solar cells. Design, fabrication, and characterization of crystalline silicon, amorphous silicon, CdTe, CIGS, and tandem and organic solar cells. Emerging solar cell concepts such as intermediate band gap and bioinspired solar cells. Emphasis is on the materials science aspects of solar cells research. Module design and economic hurdles that must be overcome for solar cell technology to generate a significant fraction of the world's electricity. Group project to explore one solar cell approach in depth. SCPD offering.
3 units, Aut (McGehee, M)

MATSCI 311. Lasers in Materials Processing
Principles of laser operation. Optically and electrically pumped lasers. Materials for solid-state lasers. Fundamentals of laser/materials interactions. Applications in thin film technology and microfabrication; laser annealing of defects and crystallization of amorphous films. Laser-induced shock waves. Extreme non-equilibrium laser processing; ultra-fast (femtosecond) lasers and their novel uses; micro- and nanofabrication of fluidic and photonic devices; intracellular nano-surgery.
3 units, not given this year

MATSCI 312. New Methods in Thin Film Synthesis
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.
3 units, Aut (Wang, S)

MATSCI 316. Nanoscale Science, Engineering, and Technology
Sample application areas: renewable energy including nanoscaled photovoltaic cells, hydrogen storage, fuel cells, and nanoelectronics. Nanofabrication techniques including: self-assembly of amphiphilic molecules, block copolymers, organic-inorganic mesostructures, colloidal crystals, organic monolayers, proteins, DNA and abalone shells; biologically inspired growth of materials; photolithography, electron beam lithography, and scanning probe lithography; and synthesis of carbon nanotubes, nanowire, and nanocrystals. Other nanotechnology topics may be explored through a group project. SCPD offering.
3 units, Spr (Cui, Y)

MATSCI 320. Nanocharacterization of Materials
Current methods of directly examining the microstructure of materials. Topics: optical microscopy, scanning electron and focused ion beam microscopy, field ion microscopy, transmission electron microscopy, scanning probe microscopy, and microanalytical surface science methods. Emphasis is on the electron-optical techniques. Recommended: 193/203.
3 units, Win (Sinclair, R), alternate years, not given next year

MATSCI 321. Transmission Electron Microscopy
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.
3 units, Win (Staff), alternate years, not given this year

MATSCI 322. Transmission Electron Microscopy Laboratory
Experimental application of electron microscopy to typical materials science studies. Topics include microscope operation and alignment, diffraction modes and analysis, bright-field/dark-field analysis of defects, high resolution imaging, and analytical techniques for compositional analysis (EDAX). Enrollment limited to 12. Prerequisites: 321, consent of instructor.
3 units, Aut (Marshall, A)

MATSCI 323. Thin Film and Interface Microanalysis
The science and technology of microanalytical techniques, including Auger electron spectroscopy (AES), Rutherford backscattering spectroscopy (RBS), secondary ion mass spectroscopy (SIMS), ion scattering spectroscopy (ISS), and x-ray photoelectron spectroscopy (XPS or ESCA). Generic processes such as sputtering and high-vacuum generation. Prerequisite: some prior exposure to atomic and electronic structure of solids. SCPD offering.
3 units, Aut (Evans, C)

MATSCI 325. X-Ray Diffraction
Diffraction theory and its relationship to structural determination in solids. Focus is on applications of x-rays; concepts can be applied to neutron and electron diffraction. Topics: Fourier analysis, kinematic theory, Patterson functions, diffraction from layered and amorphous materials, single crystal diffraction, dynamic theory, defect determination, surface diffraction, techniques for data analysis, and determination of particle size and strain. Prerequisites: 193/203, 195/205.
3 units, not given this year

MATSCI 326. X-Ray Science and Techniques
X-ray interaction with matter; diffraction from ordered and disordered materials; x-ray absorption, photoemission, and coherent scattering; x-ray microsocopy. Sources including synchrontrons, high harmonic generation, x-ray lasers. Time-resolved techniques and detector technology.
3 units, Aut (Lindenberg, A)

MATSCI 343. Organic Semiconductors for Electronics and Photonics
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. SCPD offering.
3 units, Spr (Salleo, A; Peumans, P)

MATSCI 346. Nanophotonics
(Same as EE 336) Recent developments in micro- and nanophotonic materials and devices. Basic concepts of photonic crystals. Integrated photonic circuits. Photonic crystal fibers. Superprism effects. Optical properties of metallic nanostructures. Sub-wavelength phenomena and plasmonic excitations. Meta-materials. Prerequisite: electromagnetic theory at the level of 242.
3 units, Win (Fan, S; Brongersma, M)

MATSCI 347. Introduction to Magnetism and Magnetic Nanostructures
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, and applications of magnetic materials, especially magnetic nanostructures and nanotechnology. Tools include finite-element and micromagnetic modeling. Design topics include electromagnet and permanent magnet, electronic article surveillance, magnetic inductors, bio-magnetic sensors, and magnetic drug delivery. Design projects, team work, and computer-aided design. Prerequisites: PHYSICS 29 and 43, or college-level electricity and magnetism.
3 units, Spr (Wang, S; White, R)

MATSCI 351. Failure Analysis for Emerging Technologies
Introduction to root cause failure analysis investigation of emerging technologies such as high tech electronic and medical devices. Real case studies illustration of design errors, manufacturing defects, misuse and environmental degradation that resulted in fracture, fatigue, cracking or corrosion. Understanding material degradation modes and mechanisms. Examples on analytical characterization techniques such as scanning electron microscopy (SEM), X-ray photoelectron spectroscopy (XPS), Fourier transform infrared spectroscoopy (FTIR), time of flight secondary ion mass spectroscopy (TOF-SIMS), mechanical testing, finite element analysis (FEA) and electrochemical tesing.
3 units, Aut (Staff)

MATSCI 353. Mechanical Properties of Thin Films
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.
3 units, Win (Nix, W)

MATSCI 358. Fracture and Fatigue of Materials and Thin Film Structures
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.
3 units, Spr (Dauskardt, R)

MATSCI 359. Crystalline Anisotropy
(Same as ME 336) 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.
3 units, not given this year

MATSCI 380. Nano-Biotechnology
Literature based. Principles that make nanoscale materials unique, applications to biology, and how biological systems can create nanomaterials. Molecular sensing, drug delivery, bio-inspired synthesis, self-assembling systems, and nanomaterial based therapies. Interactions at the nanoscale. Applications and opportunities for new technology.
3 units, alternate years, not given this year

MATSCI 381. Biomaterials in Regenerative Medicine
(Same as BIOE 361) 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.
3 units, Win (Heilshorn, S; Cochran, J), alternate years, not given next year

MATSCI 399. Graduate Independent Study
Under supervision of a faculty member.
1-10 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

MATSCI 400. Participation in Materials Science Teaching
May be repeated for credit.
1-3 units, Aut (Staff), Win (Staff), Spr (Staff)