MATERIALS SCIENCE AND ENGINEERING

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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 the structure and properties of solids. It brings together in a unified discipline the developments in physical metallurgy, ceramics, and the physics and chemistry of solids. 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. 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 Thomas F. Peterson Engineering Laboratory (Building 550), with extensive facilities in the newly renovated McCullough building and the new McCullough Annex. Between Peterson and the new McCullough complex are housed offices for the chair and most of the faculty, for the administrative and technical staff, and for most graduate students, along with a number of 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 Complex is also the home for the Center for Research on Information Storage Materials (CRISM) with corresponding facilities for magnetic measurements. The Rapid Prototyping Laboratory (RPL), housing material deposition and removal stations, is a joint facility with Mechanical Engineering, and is housed next to the Peterson Labs in Building 530. The department maintains two microcomputer clusters for its students, one with a number of Macintosh and Windows computers, and the other with five HP and DEC workstations. Both clusters are linked with the worldwide Internet network.

Depending on the needs of their program, students and faculty also conduct research in a number of other departments and independent laboratories. Chief among these are the Center for Integrated Systems (CIS), the Center for Materials Research (CMR), and the Stanford Synchrotron Radiation Laboratory (SSRL).

The Center for Integrated Systems (CIS) 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, CIS provides start-up research funds and maintains a "Fellow-Mentor" program with industry.

For information on CMR and SSRL, see the "Center for Materials Research" and "Stanford Synchrotron Radiation Laboratory" sections of this bulletin.

UNDERGRADUATE PROGRAMS

BACHELOR OF SCIENCE

The undergraduate program provides training in solid state fundamentals and in physical metallurgy. 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" 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 an MSE minor, see the "School of Engineering" section of this bulletin.

COTERMINAL B.S./M.S. PROGRAM

Stanford undergraduates who wish to continue their studies for the Master of Science degree in the coterminal program should apply for entrance after the beginning of the eighth quarter of undergraduate work and before the end of the eleventh quarter. The application must give evidence that the student possesses the potential for strong academic performance at the graduate level. Each application is evaluated by the department's Admissions Committee. 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 Resource Center, room 550B, or from Degree Progress in the Registrar's Office, Old Union. Students entering the coterminal program and receiving both their B.S. and M.S. degree in Materials Science and Engineering should also see the "Master of Science for MS&E Coterminal Students" section below.

GRADUATE PROGRAMS

Graduate students can specialize in any of the areas of materials science and engineering. In collaboration with other departments of the University, additional special programs are available.

MASTER OF SCIENCE

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 (MSE) requires a minimum of 45 units for a master's degree. Up to 9 units of work done as a graduate student at another institution may sometimes be transferred to give unit credit toward the electives used in acquiring a Stanford degree. Substitution of courses taken for specific Stanford courses is approved on the Master's Program Proposal. Master's Program Proposal forms should be filled out, signed by the students' academic adviser, and submitted to the department's Student Services Coordinator by the end of the first week of the students' second quarter of study. (Generally, this means by the end of the first week of Winter Quarter.) Final changes to the master's program must be submitted *no later* than one academic quarter prior to degree conferral.

Degree requirements (for students entering after September 1, 1997) are as follows:

1. A minimum of 33 units of MSE course work, including cross-listed courses, taken for a letter grade. The following are limitations:
   a) A maximum of 9 units of cross-listed courses may be used in fulfilling this requirement.
   b) One-unit seminars and research units cannot be used to fulfill this requirement.
2. Lab courses MSE 171, 172, 173 (which count toward the required 33 units of MSE course work).
   Note: students who have had equivalent lab courses at other universities, equivalent practical experience, or have a materials related degree or background are *expected* to file a petition with the department's Student Services Coordinator to have this requirement waived.
3. Six courses selected from MSE 152, 251, and 201 through 209. These "core" courses count towards the required 33 units of MSE course work, however:
   a) MSE 152 is *not* an option for students with materials science undergraduate degrees.
   b) MSE 251 may *not* be used to fulfill this "core" requirement if the student has a materials science undergraduate degree, although it may be applied towards the required 33 units of MSE course work,
4. Approved course electives to bring total units to 45. Of the 12 units of elective courses:
   a) Nine of the 12 units must be taken for a letter grade.
   b) A maximum of 3 units may be seminars.
   c) If writing a Master's Research Report, a minimum of 6 and a maximum of 9 units of MSE Research units may be used.
   d) A maximum of 3 units may be undergraduate units (offered at Stanford University).
   e) A maximum of 5 units may be used for a foreign language course (not including any remedial English courses).
   f) The combination of seminar, undergraduate, and language units may not exceed 6 units total.
   g) The combination of research, seminar, undergraduate, and language units may not exceed 12 units total. (Research units are only allowed when writing a Master's Research Report.)
5. A minimum grade point average (GPA) of 2.75 for course work at Stanford.

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

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

When a student is admitted to the graduate program, he or she is admitted specifically into either the M.S. or 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 can 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, and two letters of recommendation from members of the Stanford faculty, including one from the student's prospective adviser and at least one from an MSE faculty member belonging to the Academic Council.

The M.S. to Ph.D. Transfer Petition is due to the Student Services Coordinator 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 3.25 or better in the first two quarters of the core-course sequence is required.

Transferring to the Ph.D. program is a competitive process and only fully qualified M.S. students are admitted. The Admissions Committee and the department chair consider the student's original application to the graduate program as well as the material provided with the transfer petition. Decisions regarding these petitions are normally available by the fourth week of Spring Quarter.

MASTER'S RESEARCH REPORT

Students wishing to take this option must submit a program of study, including not more than 9 and no less than 6 MSE research units, to the department for approval at least two quarters before the degree is granted. The total combined units of MSE research units, seminars, language courses, and undergraduate courses cannot exceed 12. If a master's research report is not to be submitted, units of MSE 200 cannot be applied to the department's requirement of 45 units for the master's degree.

The report must be approved by two faculty members. One faculty member is the student's research adviser. The other faculty member is assigned by the department. Three copies of the report (one copy for each approving faculty member and the department library), in final form and signed by two faculty members, must be in the hands of the department's Student Services Coordinator one week prior to the beginning of the final examination period of the final quarter of the program. The report is not an "official" University thesis but rather is intended to demonstrate to the department faculty an ability to conduct and report directed research. The Master's Report is not appropriate for students wishing to petition for the Ph.D. program. Refer to the *Materials Science and Engineering Student Handbook* for more information and further clarification concerning this report.

M.S. FOR MSE COTERMINAL STUDENTS

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 (MSE) requires a minimum of 45 units for a master's degree. Students who have received or are currently working towards a B.S. degree in Materials Science and Engineering from Stanford and are pursuing a M.S. in Materials Science and Engineering should follow the requirements below in lieu of those stated in the "Master of Science" section listed above. Master's Program Proposal forms should be filled out, signed by the students' academic adviser, and submitted to the department's Student Services Coordinator by the end of the first week of the students' second quarter of study. (Generally, this means by the end of the first week of Winter Quarter.) Final changes to the master's program must be submitted *no later* than one academic quarter prior to degree conferral.

Degree requirements (for students who entered after September 1, 1997) are as follows:

1. A minimum of 21 units of MSE course work taken for a letter grade. Crosslisted courses, 1-unit seminars, research units and/or MSE 400 cannot be used to fulfill this requirement. These 21 units of MSE courses must include:
   a) The three remaining core classes (MSE 191/201 to 199/209) not taken for the B.S. degree in MSE.
   b) Twelve units of non-crosslisted MSE 300-level courses (not including 300).
2. Approved course electives to bring the total units to 45. Of the 24 units of elective courses:
   a) Twenty-one of the 24 units must be taken for a letter grade.
   b) A maximum of 3 units may be seminars.
   c) If writing a Master's Research Report, a minimum of 6 and a maximum of 9 units of M.S. research units (MSE 200) may be used.
   d) A maximum of 6 units may be undergraduate units.
   e) A maximum of 5 units may be used for a foreign language course (not including any remedial English courses).
   f) The combination of seminar, undergraduate, and language units may not exceed 9 units total.
   g) The combination of research*, seminar, undergraduate, and language units may not exceed 15 units total.
3. A minimum grade point average (GPA) of 2.75 for course work at Stanford.

* See the Master's Research Report section listed above, noting the additional unit privileges allotted to coterminal students. See the department's Student Services Coordinator for more information and/or clarification on what constitutes an approved course.

ENGINEER

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 substantial equivalent requirements of the M.S. in Materials Science and Engineering, and must file with the department's Student Services Coordinator a petition requesting admission to the program, as well as stating the type of research to be done and the professor who will be supervising. Once approved, the Application for Candidacy must be submitted to the department's Student Services Coordinator 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.

A program should include 9 units of graduate non-crosslisted courses in materials science (exclusive of research units, seminars, colloquia, MSE 400—Participation in Teaching, and so on) beyond the requirements for the M.S. degree, and additional research or other units to meet the 36-unit University minimum requirement. A grade point average (GPA) of 3.0 must be maintained for all 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. A petition is required for non-Academic Council members.

DOCTOR OF PHILOSOPHY

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

Degree requirements (for students entering after September 1, 1996) are as follows:

1. Complete the requirements for the M.S. in Materials Science and Engineering (MSE), unless receiving residency credit for completing a master's degree elsewhere.
2. Pass a departmental oral qualifying examination the second year after admission. A GPA of 3.25 from the nine core classes (201-209) is required for admission to the Ph.D. qualifying exam. Students whose GPA is between 3.00 and 3.25 may petition for possible admission to the exam. Students who have passed the departmental oral examination 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.
3. Submit a program consisting of at least 72 units, which contains a minimum of 57 technical course units. Of these 57 units, 42 must be taken as non-cross listed MSE courses. A maximum of 12 units of cross-listed MSE courses can be applied toward this requirement, and 9 units of non-MSE technical courses can be used. The 42 units of MSE courses must be taken for a letter grade. The remaining units may consist of research, seminars, language classes, and so on. The program for the M.S. and Ph.D. combined must include the following:
   a) MSE 201 through 209 (27 units), except for students who have had equivalent courses at other universities and have successfully petitioned out.
   b) A minimum of 12 units of 300-level courses from the MSE faculty (not including MSE 300).
   c) A minimum of 12 units of courses taken from one of the following lists of Advanced Specialty Courses (see below). Some and/or all of these courses can be the same as the courses used to meet requirement '3b' above; however, the units may not be counted twice.
4. Maintain a GPA of 3.0 for all course work taken as a graduate student at Stanford.
5. Present the result of the dissertation at a department seminar immediately preceding the University Oral examination.

ADVANCED SPECIALTY COURSES

Electronic Materials Processing: Elect. Engr. 212, 216, 217, 311, 316, 410

Materials Characterization: Elect. Engr. 329, 331; MSE 320, 321, 322, 323, 324, 325

Mechanical Behavior of Solids: Aero. & Astro. 252, 256; MSE 251, 270, 350, 351, 352, 353, 354, 355, 356, 358, 359; Mech. Engr. 235A,B,C, 238A,B

Physics of Solids: App. Phy. 372; Elect. Engr. 216, 312, 316, 331; MSE 228, 322A,B, 327, 329, 332, 335, 347, 348, 349, 359

Synthesis and Processing Materials: Chem. Engr. 310A, 310B, 340, 345, 460; MSE 313, 315; Mech. Engr. 262A

COURSES

(WIM) indicates that the course meets the Writing in the Major requirements.

(AU) indicates that the course is subject to the University Activity Unit limitations (8 units maximum).

PRIMARILY FOR UNDERGRADUATES

50. Introductory Science of Materials—(Enroll in Engineering 50.)
4 units, Win (Bravman)
Spr (Sinclair)

100. Undergraduate Independent Study—Independent study in materials science under supervision of a faculty member.
1-3 units, any quarter (Staff)

150. Undergraduate Research—Participation in a research project.
3-6 units, any quarter (Staff)

151. Microstructure and Mechanical Properties—For undergraduates; see 251. Prerequisite: Engineering 50 or equivalent.
3 units, Aut (Dauskardt)

152. Electronic Materials Engineering—Materials engineering for information technology applications. The fundamental electrical, optical, and magnetic properties of materials. Production of semiconductor crystals: bulk crystal growth, thin film synthesis. Semiconductor processing: oxidation, diffusion, ion implantation. Production of integrated circuits: lithography, metallization, packaging, testing, and reliability. Optical materials processing and applications. Magnetic and magneto-optic materials for information storage. Emphasis is on the practical application of knowledge to materials and process design. Recommended: Engineering 50 or equivalent.
3 units, Spr (McIntyre)

159Q. Stanford Introductory Seminar: Research in Japanese Companies—Preference to sophomores. The home-campus equivalent of the course taught at Kyoto. Knowledge from this research, and company visits, is evaluated in a seminar/discussion setting. Lecture/discussion on the structure of a Japanese company from the point-of-view of Japanese society. Visiting researchers from Japanese companies, with brief presentations and extensive question and answer periods, explore the Japanese research ethic.
3 units, Spr (Sinclair)

161. Materials Science Lab I—For undergraduates. The development of standard lab procedures for materials scientists, with an emphasis on metallography. Metallographic sample preparation, optical and scanning-electron microscopy, heat treatment of materials, scanning-probe microscopy. (WIM)
4 units, Aut (Doan)

162. Materials Science Lab II—For undergraduates. Experimental techniques for microstructural analysis of materials. Powder and single-crystal x-ray diffraction; transmission electron microscopy. Prerequisite: 193/203.
4 units, Win (Doan)

163. Materials Science Lab III—For undergraduates. Lab on experimental techniques for the study of the mechanical properties of materials, including fracture toughness testing of metallic materials, ductile-to-brittle transition curves, fracture of ceramics using indentation techniques, and effects of grain size on yielding and strain hardening. Prerequisites: 198/208, 151/251, or equivalent.
4 units, Spr (Nix)

169Q. Stanford Introductory Seminar: Issues in Science and Christianity—Preference to sophomores. Insights as provided by modern science and the Christian perspective, and ways to integrate them. Seven patterns that have been used in the effort to describe the interaction between them. Consideration of contemporary issues such as creationism vs. evolution, determinism vs. free will, issues at the beginning and ending of life, and responsibility for the environment.
3 units, Win (Bube)

170. Materials Selection in Design—For undergraduates; see 270. Prerequisites: Engineering 14 and 50 or Mechanical Engineering 111.
3 units (Prinz) alternate years, given 2001-02

171. Materials Science Lab I—For graduates; see 161. Prerequisite: Engineering 50 or equivalent.
3 units, Aut (Doan)

172. Materials Science Lab II—For graduates; see 162. Prerequisite: 193/203.
3 units, Win (Doan)

173. Materials Science Lab III—For graduates; see 163. Prerequisites: 198/208, 151/251, or equivalent.
3 units, Spr (Nix)

179Q. Stanford Introductory Seminar: Materials in Sports—Preference to sophomores. Introduction to materials science using sporting equipment as a vehicle to highlight material properties, performance, and selection criteria. The classes of material, and the properties relevant to sporting equipment performance. Examples from modern sporting equipment (golf clubs, tennis rackets, skis, and bicycles) highlight the relationship between material properties and product performance.
3 units, Spr (Clemens)

191. Mathematical and Computational Methods in Materials Science—For undergraduates; see 201. Prerequisite: familiarity with ordinary differential equations.
4 units, Aut (Barnett)

192. Solid State Thermodynamics—For undergraduates; see 202**.** Prerequisite: physical chemistry or introductory thermodynamics.
4 units, Aut (Musgrave)

193. Atomic Arrangements in Solids—For undergraduates; see 203.
4 units, Aut (Sinclair)

194. Phase Equilibria—For undergraduates; see 204. Prerequisite: 192/202.
4 units, Win (McIntyre)

195. Waves and Diffraction in Solids—For undergraduates; see 205. Prerequisite: 193/203 or consent of instructor.
4 units, Win (Clemens)

196. Imperfections in Crystalline Solids—For undergraduates; see 206. Prerequisite: 193/203.
4 units, Win (Nix)

197. Rate Processes in Materials—For undergraduates; see 207. Prerequisites: 191/201, 192/202, 194/204.
4 units, Spr (Clemens)

198. Mechanical Properties of Materials—For undergraduates; see 208. Prerequisites: 193/203, 196/206.
4 units, Spr (Dauskardt)

199. Electrical and Magnetic Properties of Solids—For undergraduates; see 209. Prerequisite: 195/205 or equivalent.
4 units, Spr (Wang)

PRIMARILY FOR GRADUATES

200. Master's Research—Participation in a research project.
1-15 units, any quarter (Staff)

201. Mathematical and Computational Methods in Materials Science—Use of matrix and tensor analysis, with applications to the effects of crystal symmetry on physical property tensors related to elastic deformation, thermal expansion, diffusion, electricity and magnetism, piezoelectricity, and thermodynamics. Selected topics in elementary waves in solids, analytical and numerical solutions of the one-dimensional diffusion equation, or an introduction to the use of the calculus of variations. Assignments use Mathematica.
3 units, Aut (Barnett)

202. Solid State Thermodynamics—The principles of thermodynamics and relationships between thermodynamic variables. Equilibrium in thermodynamic systems. Elementary statistical thermodynamics. Thermodynamics of multicomponent systems, interfaces and defects in solids. Prerequisite: physical chemistry or introductory thermodynamics.
3 units, Aut (Musgrave)

203. Atomic Arrangements in Solids—Atomic arrangements in perfect and imperfect crystalline solids, defect chemistry, and elements of formal crystallography, including development of point groups and space groups.
3 units, Aut (Sinclair)

204. Phase Equilibria—The principles of heterogeneous equilibria and their application to phase diagrams. Elementary statistical thermodynamics. Prerequisite: 192/202.
3 units, Win (McIntyre)

205. Waves and Diffraction in Solids—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 units, Win (Clemens)

206. Imperfections in Crystalline Solids—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. Introduction to the structure and properties of interfaces in solids. Prerequisite: 193/203.
3 units, Win (Nix)

207. Rate Processes in Materials—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: 191/201, 192/202, 194/204.
3 units, Spr (Clemens)

208. Mechanical Properties of Materials—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, 196/206.
3 units, Spr (Dauskardt)

209. Electrical and Magnetic Properties of Solids—Introduction to the electronic, magnetic, optical, and ferroelectric properties of solids. Emphasis is on concepts and models of phonons and electronic energy bands as applied to metals, semiconductors, magnetic materials, and insulators. Elementary quantum and statistical mechanics concepts are utilized. Prerequisite: 195/205 or equivalent.
3 units, Spr (Wang)

220. Master's Research Project—Participation in a Master's Research Project.
1-15 units, any quarter (Staff)

227. Scattering Physics—(Enroll in Applied Physics 196.)
4 units, not given 2000-01

230. Materials Science Colloquium—Can be repeated for credit. (AU)
1 unit, Aut (Clemens, Barnett)
Win (Dauskardt, Sinclair)
Spr (McIntyre, Nix)

251. Microstructure and Mechanical Properties—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: Engineering 50 or equivalent.
3 units, Aut (Dauskardt)

255. Mechanical Properties of Composites—Introduction to composite materials and their applications. Elastic and plastic properties of structural polymers, metals, and ceramics, reinforced by fibers, laminates and dispersed particles. Application of micromechanics to the understanding of strength, fracture toughness, creep resistance, and thermal properties of composites. Synthesis, processing, and the characterization of structural composites.
3 units (Nix) alternate years, given 2001-02

260. Advanced Dislocation Theory—The mathematical theory of dislocations and how to apply it. Possible topics: elastic Green's functions, formula of Volterra and Mura, specializing the results, self-energies of dislocations in 2-D and 3-D, interaction energies in elasticity, the Lothe-Brown formula; and forces on dislocation elements due to other dislocations, surfaces, and sources of applied stress.
3 units (Barnett) alternate years, given 2001-02

270. Materials Selection in Design—Methods to select materials for engineering applications, emphasizing structural and thermal properties. Fundamentals of the interrelation between material parameters. Strategies for optimal selection subject to performance, processing, and manufacturing constraints. Materials selection with and without shape considerations. Use of materials databases. Design case studies. Material synthesis methodologies. Prerequisite: Engineering 14 and 50 or Mechanical Engineering 111.
3 units (Prinz) alternate years, given 2001-02

299. Practical Training—Provides 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. Meets the requirements for Curricular Practical Training for students on F-1 visas. Student is responsible for arranging own employment. See department Student Services Coordinator before enrolling. Can be repeated for credit.
1 unit, any quarter (Staff)

300. Ph.D. Research—Participation in a research project.
1-15 units, any quarter (Staff)

310. Integrated Circuit Fabrication Processes—(Enroll in Electrical Engineering 212.)
3 units, Aut (Plummer)

312. New Methods in Thin Film Synthesis—Techniques to grow thin films on an atomic scale provide the materials base for new classes of coatings and devices. The fundamentals of vacuum growth techniques, molecular beam epitaxy (MBE), chemical vapor deposition (CVD), ion beam assisted deposition, and plasma processes. Relationships between deposition parameters and film properties. Industrial applications of thin film synthesis.
3 units, Aut (Clemens)

313. Principles of Ceramics Processing—Fundamental description of the unit process operations used to fabricate polycrystalline ceramic components. Topics: grain growth, solid state and liquid phase sintering, drying, ceramic forming processes, beneficiation, introductory rheology, particle packing, size/shape effects, influence of processing additives, powder synthesis through solid state reactions and wet chemical methods. Prerequisites: 204 and 207, or their equivalents.
3 units, Aut (McIntyre) alternate years, not given 2001-02

315. Polymer Physics—(Enroll in Chemical Engineering 460.)
3 units, Spr (Frank) alternate years, not given 2001-02

316. Nanoscale Science, Engineering, and Technology—The techniques for patterning materials at the nanometer length scale: self-assembly, electron beam lithography, scanning probe lithography, and epitaxy. Electrical, optical, magnetic, chemical, and mechanical properties of nanostructured inorganic/organic hybrids, synthetic and biological supramolecules (e.g., dendrimers, liquid crystals, proteins, DNA), epitaxially grown films, nanoparticles, nanotubes, nanowires, self-assembled monolayers, and molecular wires. The hierarchical design of materials, molecular electronics, biomimetics, and scanning probe microscopy.
3 units, Aut (McGehee)

317. Advanced Integrated Circuit Fabrication—(Enroll in Electrical Engineering 311.)
3 units, Spr (Saraswat)

318. Integrated Circuit Fabrication Laboratory—(Enroll in Electrical Engineering 410.)
3-4 units, Win (Saraswat)

319. Electron and Ion Beams for Semiconductor Processing—(Enroll in Electrical Engineering 217.)
3 units, Spr (Pease) alternate years, not given 2001-02

320. Techniques for Microstructural Characterization of Materials—Current methods of directly examining the microstructure of materials. Topics: optical microscopy, scanning electron microscopy, field ion microscopy, transmission electron microscopy, x-ray topography, and scanning transmission electron microscopy. Emphasis is on the

electron-optical techniques. Prerequisite: 193/203.
3 units (Sinclair) alternate years, given 2001-02

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. Prerequisite: 193/203, 195/205, or equivalent.
3 units, Win (Sinclair) alternate years, not given 2001-02

323. Thin Film and Interface Microanalysis—The science and technology of a variety 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.
3 units (Kelly) alternate years, given 2001-02

324. Selected Topics in Thin Film Microcharacterization—Case-study characterizing materials, defining problems in characterizing surfaces or thin films, carrying out analyses of relevant samples, and reporting the results. Students operate modern electron, ion, and x-ray probe instruments to study samples. Methodology for approaching characterization problems; experience in interpreting and presenting experimental results. Emphasis is on the application of theoretical measurement capabilities to practical problems, and the capabilities and limitations of modern techniques. Topics: choosing the appropriate techniques, analytical pitfalls, quantitative analysis, effects of noise and other uncertainties on analytical precision. Enrollment limited. Prerequisite: 323 or consent of instructor.
3 units, Win (Kelly) alternate years, not given 2001-02

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 (Clemens) alternate years, given 2001-02

327. Scattering Physics—(Enroll in Applied Physics 218.)
3 units, not given 2000-01

330. Ceramics for Electronic Applications—Electronic and ionic conduction, dielectric, piezoelectric, and opto-electronic properties of advanced ceramic materials. Behavior of bulk polycrystalline ceramics and thin films. The relationships among processing history, microstructure, point defect chemistry, and the functional properties of ceramic. Application areas: high permittivity on-chip capacitor dielectrics, piezoelectric sensors/actuators, fast ion conductors, electrical and thermal transducers, and electro-optic devices. Prerequisite: 209 or equivalent.
3 units (McIntyre) alternate years, given 2001-02

334. Basic Physics for Solid State Electronics—(Enroll in Electrical Engineering 228.)
3 units, Aut (J. Harris)

335. Properties of Semiconductor Materials—(Enroll in Electrical Engineering 327.)
3 units, Win (J. Harris)

336. Physics of Advanced Semiconductor Devices—(Enroll in Electrical Engineering 328.)
3 units, alternate years, given 2001-02

341. Principles and Models of Semiconductor Devices—(Enroll in Electrical Engineering 216.)
3 units, Aut (Saraswat)

342. The Electronic Structure of Surfaces and Interfaces—(Enroll in Electrical Engineering 329.)
3 units, Aut (Pianetta) alternate years, not given 2001-02

343. **Organic Materials for Electronic and Photonic Devices**—The effects of chemical design and processing on the structure and properties of electrically and optically active organic materials. Emphasis is on explaining the electronic band structure, conductivity, non-linear optical activity, and luminescence efficiency of organic semiconductors. The design, fabrication, and performance of organic light-emitting diodes, lasers, field-effect transistors, photovoltaic cells, photodetectors, optical switches, and photorefractive films. Liquid-crystalline-based devices, photonic crystals, and the use of soft lithography, printing, and self assembly to pattern integrated circuits.
3 units, Spr (McGehee)

344. Solid-State Sensors and Actuators—(Enroll in Electrical Engineering 312.)
3 units, Win (Kovacs)

345. Advanced VLSI Devices—(Enroll in Electrical Engineering 316.)
3 units, Win (Wong)

347. Introduction to Magnetism and Magnetic Materials—Atomic origins of magnetic moments. Magnetic exchange and ferromagnetism. Types of magnetic order. Magnetic anisotropy. Domains, domain walls, and their origin. Hysterisis loops and their relationship to fundamental physical properties. Hard and soft magnetic materials. Demagnetization factors. Applications of magnetic materials, especially to information storage. Prerequisites: Physics 53 and 57, or equivalents.
3 units, Spr (White)

348. Principles of Magnetic Recording—Fundamental understanding and applications of magnetic recording. Read and write processes, inductive and MR and GMR heads, thin film and particular media, medium and head noise, head-media interface. Technology trends and recording system issues introduced. Prerequisite: 347 or equivalent or consent of instructor.
3 units, Aut (Wang) alternate years, not given 2001-02

349. Introduction to Information Storage Systems—(Enroll in Electrical Engineering 335.)
3 units, Win (Wang)

350. Micromechanics—Use of the theory of elasticity to discuss fields of dislocations, inclusions, inhomogeneities, and their interactions in deformable solids. Applications to the microscopic foundations of macroscopic plasticity, the effects of strain energy on morphologies associated with phase transformations, and the determination of "effective" properties of composite media. Prerequisite: any brief introduction to the theory of elasticity, or consent of instructor.
3 units, Win (Barnett)

351. Microstructural Design of Advanced Materials and Composites—Strategies for the control of mechanical properties through microstructural design in a range of engineering materials and their composites. Emphasis is on a fracture mechanics description of strengthening and toughening methods in advanced ceramics and various composites. The structural reliability of brittle materials systems and their relationship to microstructure and processing in terms of fracture statistics, and long-term properties in terms of subcritical crack-growth processes with examples and applications, including cyclic fatigue and high-temperature creep of metals and ceramics. Prerequisites: basic understanding of

materials microstructure, mechanical properties, and fracture mechanics; 251 and 358, or equivalents.
3 units, Spr (Dauskardt)

352. Stress Analysis of Thin Films and Layered Composite Media—Introduction to methods of stress analysis of layered dissimilar media, including thin films deposited on substrates, composite laminates, and stratified anisotropic elastic materials based on techniques pioneered by Stroh. Stress states generated by thermal and elastic mismatch and local stress concentrations at interfacial cracks or corners with applications to integrated circuit devices, aircraft materials, and geophysical media. Prerequisites: introductory course on the strength of materials or the theory of elasticity, some familiarity with matrix algebra.
3 units, Win (Barnett) alternate years, not given 2001-02

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 (Nix) alternate years, given 2001-02

354A. Theory and Applications of Elasticity—(Enroll in Mechanical Engineering 240A.)
3 units, Win (Gao)

354B. Introduction to Fracture Mechanics—(Enroll in Mechanical Engineering 240B.)
3 units, Spr (Gao)

355. Time-Dependent Plasticity—Theories and mechanisms of creep. Temperature and strain rate effects on the plastic flow of solids. The relation of high temperature strength and ductility of materials to structure. Prerequisite: 198/208.
3 units (Nix) alternate years, not given 2001-02

356. Fatigue Design and Analysis—(Enroll in Mechanical Engineering 245.)
3 units, Win (Nelson)

357. Physical Solid Mechanics—(Enroll in Mechanical Engineering 229.)
3 units, Spr (Cho)

358. Fracture and Fatigue of Engineering Materials—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 cleavage and ductile fracture in metallic materials and brittle fracture of ceramics and their composites. Fracture mechanics approach to toughening and subcritical crack-growth processes with examples and applications in advanced materials, including cyclic fatigue and high-temperature creep of metals and ceramics. Prerequisite: 151/251, 198/208, or equivalent.
3 units, Win (Dauskardt)

359. Crystalline Anisotropy—Introductory matrix and tensor analysis with applications to the effects of crystal symmetry on elastic deformation, thermal expansion, diffusion, piezoelectricity, magnetostriction, and thermodynamics, following a treatment at the level of Nye's text. Homework sets use Mathematica™.
3 units (Barnett) alternate years, not given 2001-02

360. Techniques of Failure Analysis—(Enroll in Aeronautics and Astronautics 252.)
2 units, Spr (Ross)

361. Mechanics of Composites—(Enroll in Aeronautics and Astronautics 256.)
3 units, Win (Springer)

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

405. Seminar in Applications of Transmission Electron Microscopy—Can be repeated for credit. (AU)
1 unit, Aut, Win, Spr (Sinclair)

459. Frontiers in Interdisciplinary Biosciences—(Cross-listed in multiple departments in the schools of Humanities and Sciences, Engineering, and Medicine; students should enroll directly through their affiliated department, if at all possible.) Introduction to cutting-edge research involving interdisciplinary approaches to bioscience and biotechnology; for specialists and non-specialists. Associated with Stanford's Clark Center for Interdisciplinary Bioscience, and held in conjunction with a seminar series meeting twice monthly during 2000-01. Leading investigators from Stanford and throughout the world speak on their research; students also meet separately to present and discuss the ever-changing subject matter, related literature, and future directions. Prerequisite: keen interest in all of science, with particular interest in life itself. Recommended: basic knowledge of biology, chemistry, and physics.
2 units, Aut, Win, Spr (S. Block)