Appendix I—C: Materials Science and Engineering Course Descriptions

(Syllabi for College of Engineering core courses are included in the college report.)

MSE 182—Introduction to Materials Science & Engineering

Catalog Data: Provides an overview of Materials Science and Engineering as a basis for understanding how structure/property/processing relationships are developed and used for different types of materials. Illustrates the role of materials in modern society by case studies of advances in new materials and processes. Laboratory/discussion periods will be devoted to demonstrations and experiments that illustrate the lectures. Design teams will analyze or synthesize objects that use materials creatively.

Prerequisite: None. *3 hours*. 3 lecture-discussion hours/week.

Textbook: W.D. Callister, Jr., "Materials Science and Engineering, An Introduction" Wiley -- 7th Edition

Course Topics:

Atoms, bonding, basic chemistry: (basic results of quantum mechanics)
Basic types of interatomic bonds: (covalent, ionic, metallic bonding, van der Waals interactions, dipolar interactions, hydrogen bonding)
Crystal structures & crystallography: (lattices, unit cells, basis, crystallographic planes, Bragg's Law)
Introduction to metals: (fcc, bcc, hcp, atomic packing, slip systems, relation to macroscopic phenomena)
Introduction to ceramics: (organizing principles, coordination numbers and atomic sizes, crystal structures, clays, zeolites and molecular sieves, ultra-hard 'covalent ceramics', macroscopic properties, crack propagation, revitrification, ceramic composites)
Disorder: (polycrystalline matter, grain boundaries, Long Range Order and Short Range Order, metallic glasses, polymeric glasses)
Defects: (point defects, diffusion, line defects, dislocations, dislocation movement)
Stress and strain: (Young's modulus, relation to interatomic potentials, strong materials, composite materials)
Introduction to polymeric materials: (polymers, Gaussian chains, entropy, elastomers, rubber elasticity, coiling times and glass transition temperatures, block copolymers, liquid crystalline polymers and strong polymer fibers, biopolymers)
Introduction to liquid crystals: (nematic, smectic, cholesteric mesophases, lyotropics, Frederiks's transition, LCD's, soaps and membranes)
Introduction to electronic materials: (metals, semiconductors, insulators, band formation, atomic origins of band structure, relation to bonding and anti-bonding orbitals, electron mobility, doping in semiconductors, device examples)

Course Objectives:

To review physics and chemistry in the context of materials science & engineering.
To describe the different types of bonding in solids, and the physical ramifications of these differences.
To describe and demonstrate diffraction, including interpretation of basic x-ray data.
Give an introduction to metals, ceramics, polymers, and electronic materials in the context of a molecular level understanding of bonding.
Give an introduction to the relation between processing, structure, and physical properties.
Give the beginning student an appreciation of recent developments in materials science & engineering within the framework of this class.
Give the beginning student an opportunity for teamwork in research
Give the beginning student practice in basic expository technical writing.

Course Outcomes:

Given a type of material, be able to qualitatively describe the bonding scheme and its general physical properties, as well as possible applications.
Given a type of bond, be able to describe its physical origin, as well as strength.
Be able to qualitatively derive a material's Young's modulus from a potential energy curve.
Given the structure of a metal, be able to describe resultant elastic properties in terms of its 1D and 2D defects.
Given a simple set of diffraction data, be able to index the peaks and infer the structure.
Be able to describe a polymer's elastic behavior above and below the glass transition.
Be able to do simple diffusion problems.

Assessment Tools: Five quizzes (40%)
Homework (20%)
EOH term project (20%)
Attendance (20%)

Professional Component:: 100%

Prepared by: Paul Braun **Date:** April 2007

MSE 201—Phases and Phase Relations

Catalog Description: This course provides the basis for the understanding of microstructure. It treats in quantitative terms and in some depth the concept of phases (crystalline and non-crystalline structures) and the relationships between phases (phase diagrams). Commercial practices for producing desired macroscopic phase configurations and macroscopic shapes are described (processing).

Prerequisite: Chem 102, MSE 182, Physics 112, Mathematics 242. *3 hours*. 3 lecture-discussion hours/week

Textbooks: M. F. Ashby and D. R. H. Jones, Engineering Materials 2: An Introduction to Microstructures, Processing, and Design, Butterworth Heinemann (1998).

References: None

Course Topics:

Phases and phase relations
Crystal structures
Kinetics of phase transformations
Microstructures
Metals
Ceramics and glasses
Polymers and composites

Course Objectives:

The meaning of phases, and the different types of phase transformations.
How to interpret a binary phase diagram, especially the compositions and fractions of equilibrium phases according to the lever rule.
The crystal structures for common metals, ceramics, and semiconductors, including construction from a lattice plus basis, construction from hard sphere packing, and interstitial positions.
Thermodynamic driving forces and kinetic limitations in phase transformations.
The meaning and use of time-temperature-transformation diagrams.
The microstructures resulting from near-equilibrium vs. far-from-equilibrium thermal treatments.
The mechanical properties of metals, ceramics, and polymers as a function of microstructure, as determined by processing.

Course Outcomes:

Which material properties vary significantly with microstructure?
Given a binary phase diagram, what microstructures can be obtained by suitable thermal treatments? Give examples for near-equilibrium and far-from-equilibrium processing.
What are the crystal structures of the common metals and ceramics?
What crystalline structures and transformations are involved in the formation of martensites? Of age-hardened alloys?
What are the driving forces and kinetic barriers to phase transformations?
What are the governing equations for creep? For brittle fracture?
How does the modulus of a polymer vary as a function of temperature, loading rate, and cross-linking?
How are the mechanical properties of a composite material related to the properties and arrangement of the component materials?

Assessment Tools:

Six sets of homework problems, concerning both theory and applications, involving qualitative and quantitative reasoning and worked examples.
A daily "minute quiz" on the assigned reading, which obliges the students to read and think about the material *before* the lecture; the students report (by ICES) that the advance reading and thinking greatly enhances the learning process.
Two in-class hour examinations.
A short paper on a topic of their choice, within the subject areas included in the course. These papers are extensively marked by the instructor with editorial suggestions, handed back, and rewritten before a final grade is assigned.
The preparation of a poster summarizing the key points in their paper, and the presentation of this material to classmates during an in-class "poster session."

Professional Component: 100%

Prepared by: John R. Abelson **Date:** February, 2006

MSE/TAM 206—Mechanics for MatSE

Catalog Description: Topics from statics, mechanics of materials, and fluid mechanics pertinent to the fields of metallurgical engineering, ceramic engineering, and materials science and engineering: force resultants, stresses and strains produced in elastic bodies, microscopic effects of different loading states (tension, compression, torsion and bending) on deformable bodies, beam stresses and deflections, introduction to three-dimensional stresses and strains, stress and strain-rate relationships for Newtonian and non-Newtonian fluids, conservation equations (control volume analysis) for fluid flow, Reynolds number, and slow inertial and turbulent flows. This course is tailored for students with interests in materials science and engineering.

Prerequisite: Credit or concurrent registration in MSE 201. *4 hours.* 4 lecture-discussion hours/week.

Textbook: William F, Riley, Leroy D. Sturges and Don H. Morris. *Statics and Mechanics of Materials: An Integrated Approach.* New York: Wiley 2nd ed. (2001).

Recommended reading: (typical):

Round and Garg, *Applications of Fluid Dynamics,* Baltimore: Arnold (1986)
Love, *A Treatise on the Mathematical Theory of Elasticity*, 4th ed., New York: Dover Publications (1944)
Fung, *Foundations of Solid Mechanics*, Englewood Cliffs, N.J.: Prentice-Hall (1965)
Truesdell, *A First Course in Rational Continuum Mechanics*, 2nd ed., Boston: Academic Press (1991)

Course Topics:

Units and vectors
Forces, moments, couples
Equilibrium, resultants, distributed forces, free-body diagrams
Analysis of stress
Strain and stressstrain relationships
Centroids, moments
Beam stresses and deflections
Concepts of strain energy
Introduction to fluid mechanics
Properties of fluids
Hydrostatics and pressure measurement
Conservation equations
Dimensionless variables
Slow flows, inertial flows, and turbulent flows
Applications

Course Objectives:

to provide intermediate-level analysis and problem-solving methods in engineering
to give the students the basis for more advanced course work (e.g. materials processing) required for an in-depth and comprehensive program in materials science and engineering

Course Outcomes:

ability to construct free-body diagrams of mechanically loaded engineering components
ability to apply the principles of statics and strength of materials to find force resultants and internal stresses in elementary mechanical structures
ability to identify types of fluid flow and apply the principles of hydrostatics and fluid dynamics to solve elementary fluid mechanics problems

Assessment Tools:

Weekly sets of homework problems
Three one hour written exams plus 3 hour comprehensive final exam on course content designed to test the students ability to apply his/her knowledge.

Professional Component: 100%

Prepared by: Richard D. Keane & James W. Phillips **Date:** June 2007

MSE 280—Introduction to Engineering Materials

Catalog Description: Introduction to the materials science and engineering of ceramics, electronic materials, metals and polymers. Bonding; crystallography; imperfections; processing and properties of semiconductors, polymers, metals, ceramics and composites; and phase diagrams. Case studies and demonstrations will be used to exemplify the lecture material.

Prerequisites: Physics 112, 114 (concurrent), and Math 242. *3 hours* (students may not receive credit for MSE 200 and TAM 224 (CE 210) or ME 231). *3 hours*. 3 lecture-discussion/week

Textbook: "Fundamentals of Materials Science and Engineering," William D. Callister, Jr.. 2nd Ed.(special edition)

References: (available in Grainger)

Foundations of Materials Science and Engineering, William F. Smith (McGraw-Hill, 1993).
Engineering Materials and Their Applications, R.A. Flinn and P.K. Torjan (Wiley, 1995).
Engineering Materials 1, 2nd Ed., Michael Ashby and David Jones (Pergamon, 1996).
Materials Selection in Mechanical Design, 2nd Ed., Ashby (Butterworth/Heinemann, 1999).
The Principles of Engineering Materials, Barrett, Nix and Tetelman (Prentice, 1973) .

Course Topics:

Atomic Structure
Atomic bonding in solids
Metallic, Ceramic, and Polymer Structures: ionic and metallic crystal structures, polymer structures (crystalline, non-crystalline, etc.), Miller indices, diffraction.
Defects in solids: vacancies, Frenkel and Schottky defects in ionic systems, dislocations.
Diffusion: vacancy and atomic diffusion in solids (time-dependent and time-independent)
Mechanical Behavior of Metals, Ceramics and Polymers
Deformation mechanisms - metals (dislocation motion, slip, plasticity)
Strengthening/Hardening mechanisms (metals, ceramics, polymers)
Phase diagrams (phases, phase composition, composition, and microstructure)
Kinetics of phase diagrams (brief)
Fracture, crack propagation, and simple failure mechanisms (ductile-to-brittle transitions, leak-before-fail criterion, etc.)
Composites (isoload and isostrain cases, laminates)
Simplified materials selection for design, with examples (e.g., use of Ashby plots, design of leak-before-fail vessels, strong but light, low-deflection/no-fail, cost optimization, etc.).

Course Objectives:

To recall chemical bonding, types of bonds, and arrangement of periodic table.
To understand the correlation between bonding and structure, and bonding and properties.
To introduce concept of crystal structure, and the myriad of structures possible in metals and ceramics, as well as crystalline polymers, including crystal planes and diffraction.
To introduce the physical origin of and demonstrate the correlation between structure and properties of materials.
To introduce common crystal defects and to understand their role in materials behavior.
To provide overview of mechanical behavior of ceramics, metals, and polymers, including concepts of stress-strain curves, elastic response and Poission effect, yielding, necking, fracture, slip via dislocations, ductility, brittleness, strengthening mechanisms, transformation toughening, cross-linking polymers, polymer confirmations. To know how to estimate the effects of the physical effects on mechanical behavior.
To introduce students to the concept of phases and phase diagrams, including T-c behavior leads to different microstructures and, hence, varying mechanical behavior due to heat treatment. To understand effects of composition on structural and mechanical behavior, as well as how process history effects materials properties.
To introduce and utilize simple concepts of crack propagation, fast-fracture, and failure. To provide failure examples and motivate importance of materials properties in design (e.g., importance fracture toughness, KIc,).
To introduce mechanical response of composite materials and to use this information in simple examples of design and failure.
To use simplified materials selection concepts for design purposes.
To give student broad introductory knowledge of how materials properties ultimately affect engineering design in their respective disciplines, and how such properties lead to limitations.

Course Outcomes:

Given type of material (ceramic, metal, polymer), identify type of bonding present, types of crystal structure expected, and expected mechanical responses.
Be able to predict expected ordered structures in specific ionic solids.
Utilize information about elastic and plastic deformation to predict loads or strains that lead to yielding, necking, or fracture. Identify generic differences between stress-strain response in ceramics, metals, crystalline and non-crystalline polymers, and tissue.
Identify common defects in a material, when they are to be expected, and know how they affect material's mechanical properties.
Know types of dislocation, how they move, what strain-fields occur and how dislocations interact, what effects are created in crystals when they move, and how they lead to plastic deformation.
Understand and identify the stress-strain response of ceramics, metals, and polymers, and know generally how these are altered by strengthening/hardening mechanisms, alloying, etc.
Be able to identify phases (and their abundance), eutectics, eutectoid, and peritectic reactions in T-c diagrams, as well as identify simple microstructures that can occur (including possible effects on mechanical response).
Utilize concepts of crack propagation and fast-fracture and ductile-to-brittle effects to predict failure of brittle solids, and experience these in simple measurement of design problem.
Utilize material index parameters to select materials appropriate to simple design problems, including yielding and fast-fracture.

Assessment Tools:

Homework problems involving application of each topic.
Three written examinations (one in-class and two more extended take-home) Exams are designed to test th student's understanding of concepts and their ability to apply his/her knowledge.

Professional Component:: 100%

Prepared by: Duane D. Johnson **Date:** April 2007

MSE 304—Electronic Properties of Materials

Catalog Description: Study of the electronic structure and bonding of materials, electrical conduction in metals and semiconductors, and dielectric and magnetic properties of solids

Prerequisites: Physics 214 and junior standing in science and engineering. Students may not receive credit for both Materials Science and Engineering 304 and Physics 460. (Students may substitute Physics 460 for Materials Science and Engineering 304 as part of the Materials Science and Engineering degree requirements.) *3 hours*. 3 lecture-discussion hours/week.

Textbook: S. O. Kasap, "Principles of Electronic Materials and Devices," McGraw Hill, 3rd edition, 2006.

Course Topics:

Quantum mechanics of matter waves
Time-independent Schroedinger equation and solutions for one-dimensional potentials
Calculation of expectation values
Hydrogen atom ground state wave functions and energies
Quantum numbers and the periodic table
H_2^+ and simple molecules, bonding and antibonding states and energy levels
Beyond hydrogen, electron spectroscopy, photoemission
Thermodynamics of the quantum mechanical free electron gas
Periodic potentials and Bloch waves
Band diagrams in one, two, and three dimensions; effective mass; holes
Semiconductor band structures; carrier densities
Extrinsic semiconductors; dopant ionization
p-n junctions; electrostatics, carrier densities, and transport
Metal-oxide-semiconductor diodes; electrostatics and carrier densities

Course Objectives:

To teach students the science of electronic structure and transport in crystals.
To extend students' knowledge of the mathematics of complex variables, probability functions, integration, and the solutions of differential equations.
To extend students' knowledge of the thermodynamics and kinetics of a classical gas.
To teach students the science and engineering fundamentals of p-n junctions, transistors, and lasers.
To extend students' knowledge and understanding of the Schroedinger equation and the quantum mechanical behavior of electrons.

Course Outcomes:

Be able to calculate the dc and ac mobility and conductivity of a material from the collision time and carrier density.
Be able to calculate probability densities and expectation values for position, momentum, and energy for a given quantum mechanical wavefunction.
Be able to use the uncertainty principle to estimate the kinetic and potential energies of a bound electron state.
Be able to describe transport in a p-n junction controlled by the minority carrier lifetime.
Be able to use simple band diagrams to understand optical activity of a semiconductor.
Be able to calculate the effective mass of a one-dimensional band structure.
Be able to describe laser action in terms of optical absorption, stimulated emission, and spontaneous emission.
Be able to calculate charge densities in a biased metal-oxide-semiconductor diode.

Assessment Tools:

Weekly problem sets (10%)
Regular quizzes (15%)
Three, one hour exams (25% each)

Professional Component: 100%

Prepared by: John Weaver **Date:** September 2006

MSE 307—Materials Science and Engineering Laboratory I

Catalog Description: Laboratory course to learn basic experimental skills and to introduce basic instruments in materials science and engineering. Use of optical, electrical, thermal and mechanical techniques to investigate composition, structure, thermodynamic and kinetic processes of materials. Communicate laboratory findings through written reports and oral presentation.

Prerequisites: Completion of campus Composition I requirement; credit or concurrent registration in MSE 401, and MSE 405, and I E 330. *3 hours*. 2 lecture hours, 2 laboratory hours/week

Textbook: Lab Manual

References: Listed in the Lab Manual (Numerous reference texts and Handbooks are also on reserve in Grainger Engineering Library)

Course Topics:

Introduction to Basic Laboratory Instruments
Data Acquisition and Analysis
Metallography using Optical Microscopy
Cooling Curves of Binary Alloys
Scanning Electron Microscopy
Fourier Transform Infrared Spectroscopy
Thermomechanical Analysis
Thermogravimetric Analysis
Differential scanning calorimetry
Technical writing and presentation

Course Objectives:

The overall objective of the course is to provide the students with hands-on experience in (1) basic experimental techniques (2) data analysis and (3) writing journal-quality report. Small groups of about 5 to 6 students work as teams in each laboratory session with the reports prepared independently. The main objectives of the course are

To learn the principles of materials science and engineering though lab investigation;
To learn the basic skills required to properly use materials science instruments;
To learn to organize the lab results into a logic, concise and accurate report;
To develop writing and communications skills for a persuasive presentation of technical materials.

The specific objectives are given below for each experiment.

Introduction to Basic Laboratory Instruments: Introduction to the use of voltmeters, oscilloscopes, scales for mass, micrometers for length.

Data Acquisition and Analysis: Introduction to the computer-based data acquisition and analysis (DAA) system. Use of PC-based DAA for temperature measurements.

Metallography using Optical Microscopy: Learning the metallurgical sample preparation techniques: cutting, mounting, grinding and polishing. Characterization of microstructure using optical microscope.

Scanning Calorimetry and Cooling Curve: To obtain the melting point and the heat of fusion for two metals elements. Using cooling curves and calorimeter to obtain a binary phase diagram.

Thermomechanical Analysis: Measure the coefficient of thermal expansion for two known elemental metals and several specialty alloys. Determine the expansion behavior and softening point of glass

Thermogravimetric Analysis: Determine the stoichiometric relationship for the decomposition of hydrated calcium oxalate.

Fourier Transform Infrared Spectroscopy (FTIR): Introduction to spectroscopy techniques using a variety of organic specimens such as polystyrene.

Scanning Electron Microscopy (SEM): Growth of Cu films using electroplating techniques. Confirm Faraday's law relating the material deposited and the product of current and time. Learning the SEM sample preparation techniques, principles of SEM operation, examination of various samples under different SEM conditions and capture of good SEM micrographs.

Technical communications: composing formal technical reports in journal-paper style and making a short technical presentation of laboratory results.

Course Outcomes: Ability to prepare formal laboratory reports describing the results of experiments;
Ability to operate basic instruments in materials science and engineering;
Ability to interpret the data from the experiments.

Assessment Tools: Direct supervision of lab sessions to ensure every student's participation and completion of each experiment;
Six laboratory reports and a final presentation to assess the student's performance in the laboratory, ability to compose technical report and present technical results, and technical understanding.
After the first lab report has been graded a one-on-one meeting (1/2 hour) is held with each student to assess the students composition skills and to provide feedbacks to the students
6-8 quizzes given throughout the semester to assess student's preparation for individual labs and understanding of the concepts and principles.

Professional Component: 100%

Prepared by: Jian Ku Shang **Date:** April, 2007

MSE 308—Materials Science and Engineering Laboratory II

Catalog Description: Experiments to characterize mechanical, transport, and magnetic-electric properties of materials. Investigate relationship between microstructure and properties

Prerequisite: Completion of Campus Composition I requirement; MSE 307; and credit or concurrent registration in MSE 304 and 406. *3 hours* 2 hours lecture, 3 hours laboratory/week

Textbook: Lab Manual.

References: Listed in the Lab Manual (Numerous reference texts and Handbooks are also on reserve in Grainger Engineering Library).

Course Topics:

Tensile Stress-Strain Relations
Impact and Fracture Toughness Testing
Precipitation Hardening and Microstructural Analysis
Order-Disorder Transition I: Experiment (Cu3Au)
Order-Disorder Transition II: Computer Simulation
Diffusion in Solids I: Experiment (Decarburization of High Carbon Steel)
Diffusion in Solids II: Computer Simulation
Tensile Creep
Ceramic Processing
Electrical Properties of Materials

Course Objectives: The overall objectives of this course are to provide students: (1) hands-on knowledge and experience in the measurement of various material properties; (2) tools for the analysis and interpretation of data and (3) opportunities and feedbacks to improve their technical writing skills. The specific objectives of each experiment are given below. Small groups of about 5 to 6 students participate as teams in each laboratory session with the reports prepared "independently"

Tensile Stress-Strain Relations: To measure the tensile properties of several engineering materials. To investigate the relationship between strength, ductility, and fracture surface appearance in materials with a range of mechanical behaviors

Impact and Fracture Toughness Testing: To measure and compare the impact toughness of several different materials. To become familiar with the standard toughness measuring tests. To investigate the ductile/brittle transition in engineering materials.

Precipitation Hardening and Microstructural Analysis: To investigate age-hardening in aluminum alloy. To relate the microstructural changes with the aging curve.

Order-Disorder Transition I: Experiment (Cu3Au): To study the order-disorder transition in Cu-Au alloy. To investigate the order-disorder kinetics in Cu3Au

Order-Disorder Transition II: Computer Simulation: To introduce the basic concepts and the tools of computer simulation through simple exercises. To simulate order-disorder transition. To compare the simulation with the experimental results

Diffusion in Solids I: Experiment (Decarburization of High Carbon Steel): To determine the diffusion coefficient of carbon in g-Fe. To compute the activation energy of carbon diffusion in g-Fe by measuring the diffusion coefficient at various temperatures

Diffusion in Solids II: Computer Simulation: To reinforce the understanding of fundamental atomic processes of diffusion in solids through simple exercises. To correlate the simulation and experimental results

Tensile Creep: To observe various stages of creep in metals at different temperatures. To determine stress exponent and the activation enthalpy for creep in pure A

Ceramic Processing: To introduce the basic concepts of slurry preparation, spray drying, dry pressing, binder burn-off and sintering processes. To investigate the sintering kinetics of ZnO

Electrical Properties of Materials: To investigate charge transports in materials and observe the major differences among metals, semiconductors and insulators by evaluating their resistivities as a function of temperature.

Course Outcomes: Ability to prepare formal laboratory reports describing the results of experiments;
Ability to operate basic instruments in materials science and engineering;
Ability to interpret the data from the experiments.

Assessment Tools: Direct supervision of lab sessions to ensure every student's participation and completion of each experiment;
Six laboratory reports and a final presentation to assess the student's performance in the laboratory, ability to compose technical report and present technical results, and technical understanding.
After the first lab report has been graded a one-on-one meeting (1/2 hour) is held with each student to assess the students composition skills and to provide feedbacks to the students
6-8 quizzes given throughout the semester to assess student's preparation for individual labs and understanding of the concepts and principles.

Professional Component: 100%

Prepared by: Jian Ku Shang **Date:** April, 2007

MSE 395—Materials Design

Catalog Description; Design of various engineering devices, objects, or systems. Teams of 2-5 students from different concentrations within the department work toward the development of materials-based solutions to problems originating from student, faculty, and industrial suggestions. Projects will be guided by various faculty within the department, with the teams presenting mid-term (oral) and final reports. Solutions are to be based on the knowledge, skills, and design experience acquired in earlier course work and incorporate engineering standards and realistic constraints including most of such factors as economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political concerns.

Prerequisites: One of MSE 422, MSE 441, MSE 453, MSE 460, MSE 462, MSE 470. *1 hour*. Class meetings first week, midterm (progress report)s and during finals (final report); otherwise team meetings

Textbook: Class notes and notes from prior design courses (MSE 422, 441, 453, 460, 462 and 470)

Course Topic: Team based design project based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints including most of such factors as economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political concerns. It complements MSE current concentration specific courses incorporating design, all of which are offered in the Fall semester, incorporate a concentration specific design project and thus serve as an introduction to design. The projects may include, e.g.;

- design of an artifact for a particular end use.
- design and evaluation of a material for a specific application;
- reverse engineering and design improvements involving materials;
- design and evaluation or optimization of a materials processing method;
- design of a method for determining, controlling, or selecting materials characteristics or properties;
- performance of a series of documented and evaluated design activities in these or other areas throughout a student's undergraduate program and continuing into the senior year as a culminating design experience that provides experience at least equivalent to a single, senior-level design project.

Course Objectives: To work effectively in teams
To apply the knowledge and skills acquired in earlier course work to an appropriate design project.
To improve communication skills

Course Outcomes: Team presentation of design project.
Evaluation of group member contributions.

Assessment Tools: Evaluation of individual contributions by other members of the team and the advisor.
Final oral and "written" (with notes) Power Point report.

Professional Component: Engineering Topics 100%

Prepared by: Phillip Geil **Date:** March 2007

MSE 401—Thermodynamics of Materials

Catalog Description	Examines basic thermodynamics principles including energy, entropy, and free energy; describes the macroscopic properties of various materials systems such as equilibrium states, phases and phase transitions; emphasizes metals, ceramics, polymers, and electronic materials. Particular attention is paid to the application of phase diagrams; introduces the statistical interpretation of thermodynamics on the atomistic level.
Prerequisites	*Prerequisite*: Chemistry 102, Physics 107; and Mathematics 242 or 285 *4 hours* 4 hours lecture-discussion/week.
Textbook:	Introduction to the Thermodynamics of Materials, 3rd edition D. Gaskell, Taylor and Francis
References:	DeHoff: Thermodynamics in Materials Science
Course Topics	1st and 2nd Laws of Thermodynamics Statistical interpretation of entropy Auxiliary functions: free energy, chemical potential, etc. Phase equilibria in one-component systems Behavior of solutions Free energy diagrams and phase diagrams Reactions involving gases and gases with condensed states Thermodynamics of point defects: one component and stoichiometric compounds Electrochemistry
Course Objectives:	To provide a foundation for the principles of thermodynamics To provide a firm understanding of unary and binary phase diagrams To provide a working knowledge of chemical reactions: use of Ellingham diagrams To provide a consistent picture of thermodynamics concepts when applied to various topics To provide the background for other courses in the curriculum
Course Outcomes:	Given a physical situation, analyze the conditions for phase equilibria Analyze unary and binary phase diagrams of any complexity Determine gaseous backgrounds appropriate for processing materials Understand thermodynamics for advanced courses: thin film growth, kinetics, materials synthesis, and electrochemistry
Assessment Tools:	Homework problems Quizzes over each chapter Two hourly exams and one final exam.
Professional Component:	100%
	Prepared by: Erik Luijten **Date:** May 2007

MSE 402—Kinetic Processes in Materials

Catalog Description: Studies kinetics of chemical reactions; rate equations, reaction mechanisms; transport processes; diffusion equations, atomic and molecular diffusion. Phase transformations; nucleation, crystallization, displacive, spinodal decomposition. Examines surface and interface phenomena; sintering, grain growth, recovery and recrystallization

Prerequisites: MSE 200 and MSE 301 *3 hours* . 3 lecture-discussion hours/week.

Textbook: Class handouts

Other Resources/References:
D.A. Porter and K.E. Easterling, Phase Transformations in Metals and Alloys Chapman and Hall, 2nd edition, 1992.
R. Philips, Crystals, defects, and microstructures, Cambridge Univ. Press, 2001
Robert Balluffi, Samuel Allen, W. Craig Carter, Kinetics of materials, Wiley, 2005
Philip Nelson, Biological physics : energy, information, life, W. H. Freeman, 2004
Joel Gersten and Frederick Smith, The physics and chemistry of materials, Wiley, 2001

Course Topics:
Diffusion phenomenology: Fick's Laws, boundary value problems
Atomic theory of diffusion: random walks, gases, liquids, metals, grain boundaries, chemical interdiffusion, ionic crystals
Chemical rate theory: rate equations, defect annealing theory, vapor condensation
Surfaces and Interfaces: surface energies, grain boundaries, coherency, thin film growth, grain growth, sintering
Phase transformations: homo- and hetero-geneous nucleation, alloy solidification, diffusional transformations, martensitic transformations.

Course Objectives:
To provide a firm foundation of the materials science that underlies principles of kinetic behavior
To provide a firm understanding of diffusion in various materials
To provide a working knowledge of chemical rate theory
To provide an introduction to microstructure design
To provide a firm understanding of phase transformations

Course Outcomes:
Determine characteristic times for various kinetic processes
Formulate and solve rate equations for various reactions
Understand and apply basics of processing to fabricate materials with particular desired microstructures and structure-property relations
Apply basic theory to solve practical problems

Assessment Tools:
Homework problems
Midterm, final exam.
Independent oral presentation project conducted by teams

Professional Component: 100%

Prepared by: Steve Granick **Date**: May 2007

MSE 403—Synthesis of Materials

Catalog Description: Studies fundamentals of the synthesis of materials. Examines principles of synthesis; processes, approaches, synthetic methodology and probes; methodologies in materials synthesis; polymerization, sol-gel processes, liquid and vapor phase synthesis, materials coupling reactions, and precursor-derived, radiation-induced and asymmetric synthesis

Prerequisites: MSE 200 and credit or concurrent registration in MSE 301. *3 hours* 3 lecture-discussion hours/week.

Textbook: Class notes

References/(Handouts):

Materials Science and Engineering for the 1990's: Maintaining Competitiveness in the Age of Materials, Appendix A (Synthesis) & B (Processing), National Academy Press, Washington, D. C., 1989, ISBN: 0-309-03928-2.

John Wilford, "Ancient King's Legendary Gold," NY Times, August 15th, 2000

Greg Olsen, "Designing a New Material World," Science, Vol. 288, 12 May 2000, pp. 993-998

H. Remy, Treatise on Inorganic Chemistry, Vol. II: Subgroups of the periodic table and general topics, Preparation of Metals, Elsevier, 1956.

A. M. Buckley and M. Greenblatt, "The Sol-Gel Preparation of Silica Gels," Journal of Chemical Education, Vol. 71 #7, 1994, pp. 599-602

J. Livage, and C. Sanchez, "Sol-Gel Chemistry," Journal of Non-crystalline Solids, Vol. 145, 1992, pp. 11-19

J. Economy, "Now That's an Interesting Way to Make a Fiber!", Chemtech, Vol. 10, April 1980, pp. 240-247

Segal, Chemical Synthesis of Advanced Ceramic Materials, Chapter 6

P. Painter and M. Coleman, Fundamentals of Polymer Science: An Introductory Text, Chapters 1 & 2, Technomic, 1997

K. Chang, "A Prodigious Molecule and Its Growing Pains," NY Times, Oct. 10, 2000

Turner Bowden, Electronic and Photonic Applications of Polymers, Chapter 1, Section 1.1.1.1, pp. 4-11, ACS, 1998

B. G. Streetman, Solid State Electronic Devices, Fourth Edition, Chapter 1.3-1.4.4, Prentice Hall, 1995

Course Topics:

Introduction and background to Materials Synthesis
Principles of Synthesis (through case studies drawn from metal, ceramics and polymers)
General Synthetic Methodologies: preparation of metals, sol-gel synthesis, chemical conversion of a precursor fiber, chemical vapor deposition and infiltration, polymer synthesis (including an introduction to classification, nomenclature and structure).
High Strength/Modulus Materials-Synthesis and Structure
Electronic Materials – Synthetic Challenges
Design of Advanced Materials for Environmental Control
Biomaterials – Synthetic Opportunities

Course Objectives:

To present a systematic approach to the study of "synthesis" in the field of Materials Science and Engineering.
To provide students with a broad knowledge of synthetic methodologies along with an understanding of critical needs.
To provide students with examples of what's involved in designing and developing a new material through use of case studies.
To provide students with a knowledge of the field of high strength/modulus materials including preparation of single crystal ceramics and metals, phase transformation toughened ceramic; composites (both fiber and matrix) with particular emphasis on the syntheses involved.
To provide students with an understanding of the field of electronic materials and the role of synthesis in design of microelectronic chips and packaging systems.

To provide students with an awareness of the critical needs for new materials in the fields of air and water contaminant removal.
To integrate knowledge concerning structure and property relationships and how opportunities can be addressed through innovations in synthesis and processing.
To challenge students to think about materials related problems in the world around them and to come up with new materials solutions.

Course outcomes:

Given a material related problem, be able to come up with a solution by modifying the synthesis.
Given the discovery of a new or improved material, have an understanding of what is required to come up with a scalable synthesis.
From case studies on preliminary commercialization of three distinct materials, develop an understanding as to the importance of economics and design.
Given a need for a high strength/modulus product, be able to suggest an appropriate class of material.

Assessment Tools:

Three written exams plus a final
Term paper on selected materials and their synthesis. Write-ups are made accessible to the students on the web so that they can study all write-ups and be quizzed.
Some homework assignments and 3-5 minute oral quizzes at beginning of class.
Additional credit provided for student submitting a proposal for a synthetic solution to a problem.

Professional Component 100%

Prepared by: James Economy **Date:** November 2000

MSE 405—Microstructure Determination

Catalog Description: Studies the fundamentals and applications of various forms of microscopy (image formation) and diffraction for characterization of the periodic structure and defect microstructure of materials and of various forms of spectroscopy for characterization of composition, chemical bonding, and molecular dynamics.

Prerequisites: Physics 114, Chemistry 102, and Materials Science and Engineering 201. *3 hours.* 2 hours lecture, 3 hours laboratory/week.

Textbook: "The Basics of Crystallography and Diffraction," by C. Hammond (2nd edition, Oxford University Press, 2001).

References:
B. D. Cullity, "Elements of X-Ray Diffraction," Addison-Wesley, 1956.
C. J. Ball, "An Introduction to the Theory of Diffraction," Pergamon Press, 1971.
W. T. Welford, "Optics," Oxford University Press, 1981.

Course Topics:
Geometrical optics
Crystal structures
Complex notation for wave amplitudes and phase
Diffraction from one-dimensional objects and crystals
Diffraction from two- and three-dimensional crystals
Reciprocal lattices and Ewald sphere constructions for x-ray and electron diffraction
Resolution in microscopy
Contrast in microscopy: bright-field, dark-field, and phase contrast
Atomic scattering factors for photons, electrons, and neutrons
Dynamical effects: index of refraction and extinction
Core-level atomic physics and spectroscopic notation
Cross-sections for core-level impact ionization and photoemission
Microprobe analysis and x-ray photoelectron spectroscopy
Raman vibrational spectroscopy
Nuclear magnetic resonance spectroscopy and imaging.

Laboratory Work:
Optical diffraction and microscopy
(a) geometrical optics of image formation
(b) transmission and reflection microscopes
(c) diffraction from a two-dimensional crystal (TEM grid)
(d) diffraction from a one-dimensional object, coherent diffraction
(e) resolution in microscopy; bright-field, dark-field contrast
(f) characterization of colloidal crystals by optical microscopy and diffraction
X-ray powder diffraction
(a) fcc crystals and angular resolution of the diffractometer
(b) random and systematic errors, lattice parameter refinement
(c) structure factors and atomic scattering factors using NaCl structure crystals
(d) strain and peak-widths due to inhomogeneous strain and finite crystal size
(e) hcp crystals, preferred orientation in coatings
(f) x-ray absorption
Raman spectroscopy
(a) computer modeling of IR and Raman spectra of molecules
(b) Raman spectroscopy and vibrational modes of organic molecules and polymers
(c) Raman spectroscopy and vibrational modes of oxide and semiconductor crystals.
NMR spectroscopy
(a) Pulse sequencing and the determination of T_1 and T_2 relaxation times
(b) Application to the polymerization kinetics in self-healing polymers.
Computer Usage: Extensive use of Windows PCs for data acquisition and analysis.
Computer modeling of vibrational spectra of molecules.

Course Objectives:
To teach students the science of microscopy and diffraction based on the physical optics of scalar waves and elastic scattering of waves from atoms.
To teach students how the design and performance of simple microscopes and diffractometers is based in the fundamentals of geometrical and physical optics.

To teach students diffraction from simple objects and crystals in one-, two-, and three-dimensions.
To extend students knowledge of the mathematics of complex variables.
To give students hands-on experience in the operation of powder diffractometers for studying the microstructure of materials
To give students hands-on experience in the use of optical bench components for optical metrology.
To teach students the fundamentals of core-level spectroscopy for microanalysis and surface analysis.
To teach students the fundaments and applications of Raman vibrational spectroscopy.
To teach students the fundaments of NMR spectroscopy including dynamics of nuclear spins.

Course Outcomes:
Given a powder specimen of a material with a simple crystal structure, be able to collect, analyze and understand powder diffraction data.
Be able to describe the construction of transmission and reflection optical microscope, the factors that control resolution, and contrast mechanisms.
Be able to calculate intensities of a microscope image of a one-dimensional diffraction grating using bright-field, dark field, and phase contrast apertures.
Be able to use Ewald sphere constructions and calculations of structure factors to predict diffraction conditions and intensities from a three-dimensional crystal.
Be able to calculate estimates of x-ray mass absorption coefficients at x-ray energies.
Be able to calculate estimates of electron extinction lengths in transmission electron microscopy.
Be able to collect Raman spectra from polymeric materials and interpret these spectra in terms of the vibrations of molecular units.

Assessment Tools:
Weekly problem sets (15%)
Bi-weekly laboratory reports (30%)
Weekly quizzes (25%)
Final exam (30%)

Professional Component: 100%

Prepared by: David Cahill **Date:** April 2007

MSE 406—Thermal and Mechanical Behavior of Materials

Catalog Description: Studies fundamentals of elastic, viscoelastic and plastic deformation of materials, elementary theory of statics and dynamics of dislocations; examines strengthening mechanisms and behavior of composites; fracture and fatigue behavior; fundamentals of thermal behavior: heat capacity, thermal expansion and conductivity; effects of thermal stress. Credit is not given for both MSE 406 and either ME 330 or TAM 324. MSE students will not receive credit for this course toward a graduate degree.

Prerequisites: TAM 206 and MSE 301, Math 225 (Linear Algebra). *3 hours* 3 hrs. lecture-discussion/week.

Current Assigned Text: "Mechanical Behavior of Materials (2nd Edition)," Courtney

Reference Texts:
(Available Reference Desk in Grainger)

Mech. Behavior of Materials, M.A. Meyers and K.K. Chawla (Prentice-Hall, 1999)
Mechanical Behavior of Materials, Thomas Courtney (2nd Edisiton, McGraw-Hill, 2000)
Mechanical Metallurgy, George Dieter (McGraw-Hill);
Materials Science and Engineering, William Callister, Jr. (Wiley);
Engineering Materials 1, Michael Ashby and David Jones (Pergamon).
Deformation and Fracture Mechanics of Engineering Materials, Richard W. Hertzberg, 4th Edition (Wiley & Sons, NY, 1996)

Course Topics:

Material Response to Stress.
Linear Elastic Behavior
Thermal Behavior
Elements of Plasticity
Viscoelasticity Behavior
Dislocation Theory
Strengthening Mechanisms
Composite Behavior
Fracture
Fatigue Behavior

Course Objectives: To give the students a fundamental understanding of the thermal behavior (e.g., thermal stresses) and mechanical behavior (e.g., stress-strain, fatigue and fracture: or materials, and to permit processing-structure-property correlations to be drawn in subsequent senior year and/or graduate courses. While atomistics of thermal behavior are discussed elsewhere, this course is concerned with the effects on properties and giving a general knowledge of the mechanical properties of materials.

To know the generic behavior of stress-strain and thermal responses in metals, ceramics, and polymer (M-C-P), as well as the various similarities and differences of response in M-C-P.
To know the atomic-scale origin for specific aspects of stress-strain and thermal responses in M-C-P (e.g., Poisson effect, thermal expansion, independence of elastic moduli on defects).
To connect materials response under specific conditions to actual experimental set-ups.
To know differences and similarities of tensile and compressive stresses (or strains) in M-C-P and utilize concepts in plastic or brittle materials for expected stress-strain response.
To utilize knowledge of stress-strain response in M-C-P in application to simple types of processing and pre-stress/strain conditions (e.g., drawing and rolling, geometric and thermal constraints).
To know and incorporate the effect and size of thermal stresses in responses of M-C-P.
To introduce general states of stress and transformations of stress (including stress and strain invariants) for yielding and failure (e.g., Rankine, Tresca's and von Mises' criterion), necking, and response behavior of crystalline materials, as well as important differences in polymers.
To relate point, line, and planar defects to materials response in M-C-P, and to utilize this knowledge to understand and control properties. To know how such defects can be created.
To introduce and understand simple polymer, metal-matrix and ceramic-matrix composites

and their response to stress and strains

To introduce and apply fracture and fatigue behavior in M-C-P materials, with brief introduction into its use for materials design.

Course Outcomes: Given type of material (metal, ceramic, or polymer), identify elastic, plastic, and fracture regions, calculate loads required for each, use proper relations to quantify response, determine various elastic, yielding, failure behavior, especially applied to specific scenarios of processing or pre-stress/strain conditions.

Calculate thermal residual stresses and additional loads required for, say, yielding.

Identify principal stresses, strains, and planes, and calculate the stress invariants and principal quantities, planar and normal stress components in general stress states. Utilize symmetric stresses and strains, and engineering strains in mechanical response, yielding and failure.

Identify types of defects. Know generic behavior of stress fields around and interaction of defects, such solute-dislocation and dislocation-dislocation, and their effects on mechanical response in materials.

Know general iso-strain or iso-load behavior of composites and calculate responses in simple composite materials, including unaligned cases and generic effects.

Apply simple concepts of fracture, stress concentrators, and fatigue. Identify and use these concepts in simple materials design and failure.

Assessment Tools: Homework problems involving fundamental knowledge and application of each topic.

Three written examinations (two hourly and one comprehensive final) roughly divided into (1) Materials response to stress, Elasticity, Anisotropy, and Plasticity; (2) Dislocation Theory, Strengthening Mechanisms, and (3) Composite Behavior, Fracture and Fatigue. Exams are designed to test the student's understanding of concepts and their ability to apply his/her knowledge.

Professional Component: 100%

Prepared by: Duane D. Johnson **Date:** April 2006

MSE 420—Ceramics Materials and Properties

Catalog Description: Basic principles and understanding of structure-property relations in ceramic materials. Examples will be drawn from both traditional and advanced ceramics. Knowledge of structure on multiple length scales (including atomic, grain boundary, and grain structure as well as the structure of clays and amorphous materials) and several properties (including electrical, magnetic, mechanical and thermal) will be gained.

Prerequisites: MSE 182 or 200. *3 hour* 3 lecture-discussion hours/week.

Textbook: Kingery, Bowen, and Ulhmann, "Introduction to Ceramics"

Reference: Chiang, Birnie, and Kingery, "Physical Ceramics"

Course Topics:
Atomic structure, including ionic and covalent bonding, ceramic crystal structures, clay structures, and amorphous materials (network formers, modifiers and intermediate oxides).
Atomic defects, including intrinsic and extrinsic point defects, Kroger-Vink notation, defect reaction equilibria.
Electrical properties, including, dielectrics, piezoelectrics, ferroelectrics.
Magnetic properties, including ferrimagnetic materials
Microstructure development, including, solid- state sintering, densification vs. coarsening processes, grain boundary mobility, porosity evolution (stability/entrapment), viscous densification, liquid-phase sintering, constrained sintering.
Thermal properties, including heat capacity, thermal conductivity, thermal expansion, creep, and thermal stresses.
Mechanical properties including strength, toughness, and microstructural design.

Course Objectives:
Develop understanding of the structure of ceramic materials on multiple length scales.
Develop knowledge of point defect generation in ceramic materials, and their impact on transport properties.
Develop knowledge of electrical properties including examples of ceramics applications in which behavior is governed by materials structure over varying length scales.
Develop knowledge of structural evolution during sintering, including solid-state, viscous flow, and liquid- phase sintering.
Develop understanding of the magnetic, thermal and mechanical properties of ceramics.

Course Outcomes:
Knowledge of the crystal structures of a wide range of ceramic materials.
Knowledge of the structure of clays, minerals, and glasses.
Given a ceramic component be able to calculate its intrinsic and extrinsic defect populations.
Design a suitable sintering schedule for heat-treating ceramics and understand the effects of existing microstructural features (e.g., porosity, impurities, etc.) on microstructural evolution during this process.
Knowledge of properties of ceramics and their structural origin.
Familiarization with a wide array of characterization techniques.

Assessment Tools:
Homework problems focused on ceramic structure, properties, or relations between these two topics.
Two written hourly exams designed to test the student's ability to apply his/her knowledge.
One comprehensive final exam designed to test the student's ability to apply his/her knowledge.

Professional Component: 100%

Prepared by: David A. Payne **Date:** May 2007

MSE 421—Ceramic Processing and Microstructure Development

Catalog Description: Basic principles and understanding of microstructure development and processing of ceramic materials will be addressed, with an emphasis on structure-property-processing relationships. Knowledge of a variety of processing methodologies and their effects on microstructural development will be gained. Examples of several ceramic components will be illustrated and discussed within this context

Prerequisite: MSE 320. *3 hours*. To receive the additional 1 credit hour a term paper is required. 3 hours lecture-discussion/week

Textbook:: Class notes.

References:
Reed, James; Principles of Ceramic Processing 2nd Ed.
Evans, J. W./DE Jonghe, Lutgard C.; Production of Inorganic Materials
Ring, T. A.; Fundamentals of Ceramic Powder Processing and Synthesis

Course Topics:
Microstructure Development including: solid state sintering, densification vs. coarsening processes, grain boundary mobility mechanisms, porosity evolution (stability/entrapment), viscous densification, liquid phase sintering, constrained sintering.
Microstructure Characterization Methods including; microscopy techniques, quantitative image analysis (avg. grain size, distribution).
Ceramic Powders and Characterization including: conventional powders, chemically-derived powders, particle size/morphology characterization, surface area characterization, purity analysis, surface chemistry/characterization, and calcination.
Colloidal Processing including: interparticle forces, processing additives, spray drying, milling, and rheology
Forming Science including: pressing operations (dry, iso-static), slip casting, tape casting, extrusion, injection molding, hot press, HIP, emerging routes (gel-based, SFF methods), and green body characterization methods
Presintering Processes including: drying, binder removal

Course Objectives:
Develop understanding of microstructural evolution of ceramic materials
Develop working knowledge of the unit operations involved in processing ceramic materials
Develop ability to select appropriate processing methodologies based on component quantity, cost, and structure-property-processing relationships,
Develop knowledge of characterization methods used to determine microstructural features and effect of process variables
Develop ability to critically evaluate processing literature through exploration of current research articles

Course Outcomes:
Given an unknown ceramic powder be able to characterize its chemical and physical properties sufficient for its synthetic reproduction
Given a ceramic component be able to design an appropriate processing methodology for fabricating this sample
Design a suitable sintering schedule for heat treating ceramics and understand the effects of existing microstructural features (e.g., porosity, impurities, etc.) on microstructural evolution during this process
Familiarization with a wide array of characterization techniques
Ability to critically evaluate current literature in the area of ceramic processing

Assessment Tools:
Homework problems involving applications of ceramic processing topics
Two written exams on course content designed to test the students ability to apply his/her knowledge.
Written article summaries in which students must critically evaluate current journal papers published on various course topics

Professional Component: 100%

Prepared by: Jennifer Lewis **Date:** January 2001

MSE 422—Electrical Ceramics

Catalog Description: Presents the subject of dielectric crystals and their electrical properties; discussion and correlation of ferroelectric and piezoelectric properties of several crystal classes; coverage in detail of the perovskite class of ferroelectric compounds; and discussion of spinel, garnet, and hexagonal type ferrimagnetic crystals and their properties.

Prerequisites: MSE 420. *3 hours,* 3 lecture-discussion hours/ week

Textbook: "Electroceramics: Materials, Properties and Applications", A. J. Moulson and J. M. Herbert, Chapman & Hall, London, 1993 or latest edition, required; Class notes.

References:
"Ceramic Materials for Electronics", R. C. Buchanan (ed.), Marcel Dekker, New York, 1986.
"Electronic Ceramics", L. Levinson (ed.), Marcel Dekker, New York, 1988.
"Principles of Electronic Ceramics", L. L. Hench and J. K. West, Wiley Interscience, New York, 1990.
"Piezoelectric Ceramics", B. Jaffe, W. R. Cook, Jr. and H. Jaffe, Academic Press, London, 1971.

Course Topics:
Introduction: Inorganic nonmetallic materials, historical developments of electrical ceramics, functionality, R, L & C, traditional and advanced, materials, applications, useful and enabling properties.
Solid State Science---Review: insulators, dielectrics, polarization, charge displacement, dispersion, relaxation, and temperature dependence. Perovskite structure, phase transformations, domains. Dielectric mixing rules.
Processing and Fabrication: Processing cycle, materials selection, compositions, forming, thermal processing, electroding, characterization. Tape casting, mulilayers. Crystal growth.
Conductors; Heating elements, electrodes, varistors, thermistors, PTCR, ionic conductors, sensors, superconductors
Insulators and Dielectrics; Dielectric strength, capacitors, equivalent circuits, EIA classifications, high Q, temperature compensating, high -dielectric constant, boundary layer devices, design of temperature characteristics. Ferroelectricity, barium titanate.
Piezoelectrics: Point groups, structure-property relations, direct and converse effects. Thermodynamics, Heckmann diagram. Field-induced strains, voltage generation, actuators, energy conversion, applications, PZT.
Pyroelectrics: Polar point groups, thermodynamics, electrical and thermal considerations, design of a pyroelectric detector, figures of merit, materials selection.
Electrooptics: Crystal systems, optical anisotropy, birefringence, indicatrix concepts, non-linear optics, linear and quadratic effects, SHG, devices, PLZT.
Magnetics: Spinel, normal and inverse, Weiss domains, ferrites, soft and hard, super-exchange, garnets, temperature compensation, permeability, Q, microstructure-property relations, chemical substitutions, device performance, applications.

Course Objectives:
To provide students with a basic understanding of electrical ceramic materials.
To demonstrate interrelationships between structure-property relationships.
To teach the importance of the processing cycle on materials selection, thermal processing conditions, phase and microstructure development, on properties and usage.
To provide students an historical perspective of the development of functional (i.e., R, L, C) electrical ceramics.
To provide students with an appreciation for recent developments in the electrical ceramics industry.
To provide case histories of the logical design of electrical ceramics for new applications.
To challenge the students on how to make new functional materials.

Course Outcomes:
To be able to apply the principles of physical sciences and engineering to electrical ceramic systems.
To be able to integrate prior knowledge of materials science and engineering to composition-processing-structure-properties-performance relationships for electrical ceramic materials.
To be able to apply modern characterization methods for the control of the processing cycle for the reproducible manufacture of reliable and consistent electrical ceramic products.
To be able to relate important developments in the past with future needs in the electrical ceramics industry

Assessment Tools:
Frequent reading assignments from the required text, discussion in class.
Homework assignments from the required text, after each chapter.

Two hourly exams in class, written, closed book, designed to test the student's ability to apply his/her knowledge and solve problems.
A final 3-hour exam in class, written, closed book, designed to test the student's comprehensive ability to apply his/her knowledge and solve problems.
Design paper requirement of the student's choice, demonstrating the ability to design an electrical ceramic product to property specifications.

Professional Component: 100%

Prepared by: D.A. Payne **Date:** May 2007

MSE 423—Ceramic Processing Laboratory

Catalog description: (MSE 323) Experiments and demonstrations involving a wide range of modern ceramic processing methods will be conducted to develop fundamental understanding of the relationships between raw materials, processing methods, microstructural development, and physical properties. The lab emphasizes the underlying physics and chemistry of processing, as well as designing processing routes to achieve desired material properties. Technical reports will be required

Prerequisites: MSE 421. *3 hours.* 2 hours lecture and 3 hr. laboratory/wk.

Textbook(s): J. S. Read, Introduction to the Principles of Ceramic Processing, Wiley-Interscience, New York, 1995. Second edition recommended.

References:
M.N. Rahaman, "Ceramic Processing and Sintering," Marcel Dekker, Inc. (1995)
T. Ring," Fundamentals of Ceramic Powder Processing and Synthesis," Academic Press (1996)
D. W. Richerson, "Modern Ceramic Engineering, Part I (chapters 5-7), Part II (Chapters 9-13) Marcel Dekker (1982).
J.W. Evans and L. C. DeJonghe, "Production of Inorganic Materials, MacMillan (1991)
C. G. Bergeron and S. H. Risbud, "Introduction to Phase Equilibria in Ceramics," Published by The American Ceramic Society, Inc. (1984).
References to research publications taken from the Journal of the American Ceramic Society

Electronic teaching aids / computer usage: The laboratory manual and collective data from all of the class sections are posted on the website, [http://MSE323.mse.uiuc.edu/] so that students have an overview of the effect of the different parameters varied and are able to write a comprehensive laboratory report based on a broad overview.

Course topics:
Powder Synthesis
Powder Characterization
Rheology of Colloidal Suspension
Electrophoretic Deposition
Slip Casting
Pressure Filtration
Pressing
Sintering
Grain Growth
Glass Processing/Melting
Glass Annealing
Cementitious Materials and Geopolymers

Course objectives: The purpose of this course is to provide students a hands-on familiarity with the more important and widely used procedures used in processing ceramic materials used by the industry. An introduction to the theory and principles behind the processes is also provided. The course is arranged to demonstrate, in sequence, the four major steps required to produce a ceramic component.

I. Preparation of Ceramic Powders
II. Powder Characterization
III. Forming Methods (Wet and Dry)
IV. Thermal Processing

Course outcomes: Using ABET outcomes a, b, d, g, i, j, k.

Assessment tools: The grades will be computed as follows:
Lab reports (@ 15% each)90%
Pre-lab assignments and lecture homeworks and quiz 10%
The laboratory reports required will cover:
Powder Preparation and Characterization; Rheology, Slip Casting and Wet Forming Methods; Dry Pressing and Dry Forming Methods; Solid State Sintering and Constrained Sintering
In addition there will be regular pre-lab assignments.
Penalties for missing the due date for assignments and reports: A grade deduction of 0.5 % (of the total 15%) is levied per each day that the report is late after the agreed upon submission date.

Professional component: 100%

Prepared by: Waltraud M. Kriven **Date:** June 2007

MSE 440: Advanced Mechanical Properties of Solids

Catalog Description: Advanced treatment of the mechanical behavior of solids; examines crystal plasticity, dislocations, point defects and grain boundaries, creep and fatigue behavior, fracture

Prerequisites: MSE 406. *3 hours.* 3hours lecture-discussion/week.

Textbook: R. W. Hertzberg, "Deformation and Fracture Mechanics of Engineering Materials," 4th Edition, Wiley, 1996

Course Topics:

Introduction
Strength of solids
- a. Flaws in materials

Brittle Fracture
- a. Griffith theory
- b. Fracture statistics

Fracture with Limited Plasticity
- a. Linear elastic fracture mechanics
- b. Fracture toughness
- c. Microstructural aspects of fracture
- d. Environmental effects
- e. Elastic-plastic fracture

Fatigue
- a. Fatigue processes
- b. Fatigue crack initiation
- c. Fatigue crack propagation
- d. Overload effect
- e. Crack-size dependence

High Temperature Failures
- a. Creep deformation
- b. High temperature fracture
- c. Creep design

Course Objectives:

To provide an advanced treatment of mechanical properties of materials which is built on solid mechanics, defects theory, thermodynamic and kinetic principles.
To examine the roles of material defects in mechanical response of materials.
To derive the theoretical framework for analyzing the roles of material defects in influencing the mechanical properties of a solid.
To apply materials science and mechanics principles to solve engineering design problems.
To understand how mechanical behavior may be affected by microstructure, loading condition, and service environment.
To present theoretical and empirical treatments of the effects of microstructure, loading condition and service environment on mechanical behavior of materials.
To introduce students current research problems in mechanical behavior of materials.

Course Outcomes:

Able to determine dependence of material strength on flaw geometry and size;
Able to derive and apply the Griffith's theory of fracture.
Able to conduct the Weibull statistical analysis of strengths.
Able to derive and apply the energy principle of fracture.
Able to derive linear elastic fracture mechanics principles.
Able to determine fracture properties of a material.
Able to suggest microstructural changes for improving fracture properties.
Able to solve engineering problems using fracture mechanics principles.
Able to analyze stress-corrosion cracking problems.
Able to conduct fatigue analysis using stress, strain and fracture mechanics approaches.
Able to interpret fatigue data obtained under different mechanical loading conditions.
Able to suggest microstructural development to improve fatigue properties.
Able to describe creep mechanims in crystalline solids.
Able to interpret creep data and perform creep analysis.

Assessment Tools:

Weekly homework problems
A midterm examination
A comprehensive final examination.

Professional Component: 100%

Prepared by: Darrell Socie **Date:** May 2007

MSE 441—Metals Processing

Catalog Description: Discussion of melt, mechanical, thermal, powder, and surface processing of metals. Extraction of metals, joining of metals, metal composites, and metal recycling are also reviewed. The relationships between the processing of metals, the microstructures that are produced, and the behavior of metal components are emphasized.

Prerequisites: MSE 406. *3 hours*. 3 lecture-discussion hours/week

Textbook(s): Principles of Metal Manufacturing processes, Beddoes and Bibby

Other Resources/ References: (available at Grainger Library)

ASM Handbook, Desk Edition and vols. 1-20, Q.669.1Am35mabr (reference)
Manufacturing with Materials, L. Edwards, M. Endean, 670.42M4181995 (reserve)
Manufacturing Processes and Systems, P. Ostwald, J. Muñoz, 670.OS7M1997
Mechanical Metallurgy, Dieter, G. E., 3rd ed., 669.94D56m1986 (reserve)
Steels, R.W.K. Honeycombe & H.K.D.H. Bhadeshia, 669.96142h757s1996 (reference)
An introduction to Metallurgy, A. Cottrell, 2nd ed., 1975, 669.c82I1995.

Course Topics:

Metal processing and manufacturing: Materials used in manufacturing; rimary manufacturing processes-ironmaking and steelmaking; Primary manufacturing processes- aluminum production; Refining of materials
Solidification and casting processes: Major casting techniques; Solidification mechanism; Solidification volume shrinkage; Heat Transfer during solidification; Casting defects; Shape casting materials
Bulk deformation processes: Friction during bulk deformation; Forging; Extrusion and drawing; Rolling
Sheet forming processes: Formability; Shearing; Bending;
Stretch forming; Deep drawing; Effect of anisotropic sheet properties on formability
Heat treating: Phase equilibrium in Fe-C alloys; Austenitization; Transformation of austenite; Hardening; Tempering; Other processes
Powder metallurgy): Powder production; Powder characteristic; Powder compaction;
Machining: Mechanical machining methods; Nontraditional machining processes
Joining processes: Welding; Brazing; Soldering
Surface modification: Types of wear; Diffusional processes; Flame and induction hardening; Plating and thin film coating

Course Objectives:

To provide students with a broad knowledge of metals processing techniques commonly used in industry and in research laboratories, in particular extraction metallurgy, casting, forming, heat treating, powder metallurgy and surface processing.
To provide students with the chemical, physical and mechanical principles underlying these processing techniques
To demonstrate the correlation between processing conditions, microstructures and properties in common metallic materials.
To review and explain the advantages and disadvantages of the different processes studied in class..
To give the students a direct contact with several processing techniques in their industrial context.
To present methods to optimize processing parameters: work and slab methods for the calculation of forming loads, diffusion equations applied to heat treating and surface processing, chemical and electro-chemical equations to determine conditions for extraction and refining of metals from their ores or compounds.
To help students improve their writing and oral skills.

Course Outcomes:

For the following circumstance, the student should be able to:
processing technique - indicate its domain of application, its advantages and its limitations).
processing technique - identify the important chemical, physical and mechanical principles involved.
amaterial and its specifications - propose appropriate processing routes to synthesize the part.
For the student to have a comprehensive knowledge of steel processing, including iron making and steel making practices, rolling and heat treating.
For the student to identify sources of scientific and technological information on a given topic.
For the student to develop his/her writing and oral skills.

Assessment Tools: 20% Homework and participation
40% Midterm exam – Friday March 16
40% Final exam – during Finals week

Professional component: 100%

Prepared by: Pascal Bellon **Date:** May 2007

MSE 442—Metals Processing

Catalog Description: Advanced metallurgy laboratory. Examines effects of heat treatment; mechanical testing, phase transitions; oxidation and corrosion; failure analysis; and metallography of selected alloys.

Prerequisites: MSE 307, MSE 308, and MSE 440. *3 hours*. 3 lecture-discussion hours/week.

Textbook: Class notes

References: ASM Handbook, in particular vols. 4,9,10,13; handouts – various
Electronic teaching aids / computer usage: Simulation tools and data analysis software

Course Topics: 1) Austenite transformation: heat treatment, metallography, hardness to establish the TTT diagram of a low-alloy, medium carbon steel; 2) Corrosion: immersion testing vs. electrodynamic polarization; sensitization screening test of a stainless steel. 3) Recrystallization and grain growth of brass: cold rolling, heat treating, hardness measurement, metallographic characterization to study recrystallization and grain growth microstructures and kinetics. 4) Phase evolution in thin film specimens: silicide formation and crystallization of metallic glasses. 5) Industrial case studies: case study investigation, followed by results presentation at the industrial site, combined with a field trip. 6) Sand casting of Al alloys.

Course Objectives:
To provide students with a hands-on experience of characterization techniques commonly used for metallic alloys, including optical microscopy, scanning electron microscopy, x-ray diffraction, hardness and microhardness testing.
To provide students with hands-on experience with thin metal films and characterization: Rutherford backscattering spectromretry, *in-situ* electrical resistivity – van der Pauw method
To provide students with a hands-on experience of a few processing techniques commonly used for metallic alloys, including casting, heat treatment, and rolling.
To determine the correlation between processing conditions, microstructures, phase evolution, and properties in common metallic materials.
To apply the knowledge gained in previous courses on metals processing, mechanical properties, and corrosion of metallic alloys.
To give the students an opportunity to work on real-life problems (case studies, mostly failure analysis) and to interact with engineers in the companies providing the case studies.
To help students improve their writing, oral, and organizational skills.

Course Outcomes:
Given a metallic material be able to characterize the microstructure with appropriate methods and to infer the processing conditions used to obtain this microstructure.
Given a characterization technique, be able to identify its range of applicability and its limitations.
Given a used material, its specifications and its service conditions, determine the origin of its corrosion, wear or failure.
For the student to have a comprehensive and practical knowledge of a few materials processing, including heat treating, thin film deposition, and rolling.
For the student to identify sources of scientific and technological information on a given topic.
For the student to learn how to design an experiment.
For the students to develop their writing and oral skills.
For the students to develop their team working skills

Assessment Tools:
Written reports (executive summary format)
Oral presentation of case study findings.
Classroom discussion

Professional Component: 100%

Prepared by: Robert Averback **Date:** March 2007

MSE 443—Design of Engineering Alloys

Catalog Description: Examines the application of science and engineering principles to the design, selection and performance of engineering alloys. Studies alloy classes, design, effect of alloying elements, relation to processing variables and structure-property relationships; design project.

Prerequisites: MSE 340, Advanced Mechanical Properties of Solids. *3 hours* . 3 lectures per week.

Textbook: Vol. 1 and 2, ASM Handbook, ASM International, 1990

References:
other ASM Handbooks
handouts of ASTM standards, journal articles

Course Topics:
The Design Process
Steel
Cast Iron
Stainless Steel
Nickel Alloys and Superalloys
Aluminum Alloys
Copper Alloys
Titanium Alloys
Magnesium Alloys
Refractory Metals
Intermetallic Compounds

Course Objectives:
Description of how alloy design relates to component design
Application of physical metallurgy principles to the understanding of the structure-property-performance relationship
Interrelationship between processing, composition and properties
Illustration of alloy development to optimize processing and properties

Course Outcomes:
Importance of simultaneous design of alloy and processing
Knowledge of characteristics of various alloy systems and specific alloys within a given system.
Understanding of physical metallurgy principles through their application to real systems.
Selection of alloys for specific applications.
Sense of direction of alloy and process development and needs for the future

Assessment Tools:
Hour exams (3)
Term paper (one, 10-15 pages on topic of student's choosing)
Oral presentation of progress in design of specific alloys and processes (20 minutes)

Professional Component: 100%

Prepared By: Carl Altstetter **Date:** March 2001

MSE 444—Welding and Joining Processes

Catalog Description: Same as CEE 375. The physical principles of fusion welding; heat flow; thermal cycles; physical metallurgy and mechanical properties of welded joints; applications of welding to large structures; testing of welds; nondestructive testing; design, economics and weld specifications; and laboratory experiments in welding.

Prerequisites: TAM 226, 206 or equivalent. *3 hours.* 3 hours lecture-discussion/week plus laboratory time

Textbook: Cary, Modern Welding Technology, 4th Ed

References: Lancaster, The Metallurgy of Welding Brazing and Soldering

Course Topics:

Introduction: history of welding, survey of welding processes, welding terminology, welding symbols.
Common Industrial Welding Processes: oxyacetylene welding, shielded metal arc welding, gas tungsten arc welding, gas metal arc welding, resistance spot welding.
Physics of Welding: the welding arc, electrical machinery and behavior, process control, cost estimation, heat flow and temperature distributions, weld metal phenomena, contractions and residual stresses.
Weld Defects: weld cracking, weld defects, welding codes, contractions and residual stresses. nondestructive testing methods, radiographic nondestructive testing, ultrasonic nondestructive testing,, quality control and assurance.
Metallurgy of Welding: weldability of mild steel, weldability of stainless steel, weldability aluminum alloys, weldability of cast iron.
Mechanical Properties of Weldments: static design concepts, fracture mechanics, fracture control concepts, fatigue of welds.

Course Objectives: Survey important ideas and concepts associated with welding technology; Provide a bridge between the academic and real world; Act as a capstone course by integrating knowledge from many areas of natural science and engineering through the wide range of issues that arise in a discussion of welding technology; Provide a limited amount of experience welding.

Course Outcomes:

Students are familiar with all the common welding process and common welding problems associated with welding ferrous materials and aluminum alloys.
Students are aware of factors which control the cost of welding.
Students are exposed to industrial welding practices and problems during a field trip to Caterpillar Decatur that concludes the course. This field trip proves to the students that all the concepts covered in the course are critical in the manufacturing of quality heavy equipment.
Students are exposed the static and fatigue strength of weldments - one of the most important applications of fracture mechanics and the science of metallic fatigue - in the last part of the course. The students are asked to become thoroughly familiar with and comment on one of the classical studies of the failure of welded structure at the conclusion of the course.
Topics such as plasma physics, heat flow, physical metallurgy, nondestructive testing, fracture mechanics, economics, industrial safety, physical chemistry, thermodynamcs, and electrical circuits arise in the course and are integrated thorugh s in a rational discussion of welding.
Students appreciate the great skill of good welders after their attempts at welding. Students become aware of the difficulty of making good welds and why weld defects occur as frequently as they do.

Assessment Tools:

Knowledge of welding ideas tested in two hour exams and a final.
Weekly quantitative homework underscores underlying physical principles.
Bridge between academic and real world is provided by many case studies presented in lecture.
The hand-on laboratory experience with welding that includes the preparation of a weldment, which is radiographed and tested to failure in tension. Grade on this laboratory assignment is based on the quality of the weld produced.
A thorough metallurgical study of a weldment is executed by teams of students who must cooperate and write a single, well prepared report.

Professional Component: 100%

Prepared by: Frederick Lawrence **Date:** March 2001

MSE 445—Corrosion of Metals

Catalog Description: This course deals with the principles that determine the corrosion behavior of metals. Topics include electrochemistry, thermodynamics, and kinetics of corrosion. Behavior of ferrous and nonferrous metals, corrosion rates, corrosion control, cathodic and anodic protection, high-temperature corrosion, corrosion testing, and electrolytic machining methods are also discussed.

Prerequisites: Introductory materials science course, freshman chemistry and physics. *3 hours*. 4 lecture hours wk 11 weeks)

Textbook: Denny Jones, Principles and Prevention of Corrosion, McGraw-Hill, 1996

References and Supplementary Reading:

Corrosion

E. Bardal, Corrosion and Protection, Springer Verlag, New York, 2004
H. Kaesche, Corrosion of Metals, Springer Verlag, New York, 2003
E.E. Stansbury and R.A. Buchanan, Fundamentals of Electrochemcial Corrosion, ASM International, Materials Park, OH, 2000
D.A. Jones, Principles and Prevention of Corrosion, 2nd ed,. Prentice-Hall, Upper Saddle River, NJ, 1996
David Talbot and James Talbot, Corrosion Science and Technology, CRC Press, New York, 1998
J.C. Scully, The Fundamentals of Corrosion, 3rd ed., Pergamon Press, New York, 1990
K.R. Tretheway and J. Chamberlain, Corrosion, J. Wiley and Sons, New York, 1988
M.G. Fontana, Corrosion Engineering, 3rd ed., McGraw-Hill, New York, 1986
J.M. West, Basic Corrosion and Oxidation, 2nd ed, J. Wiley and Sons, New York, 1986

Journals

Corrosion; Corrosion Science; Materials Protection; J. Electrochemical Societ ; J. Applied Electrochemistry; J. Power Sources

Handbooks

Corrosion, ASM Handbook, Vol. 13 (1987), 13A(2003), 13B(2006), 13C(2006), ASM International, Materials Park, OH
G. Kreysa and M. Schutze, eds., Corrosion Handbook, second edition, Dechema, Frankfurt, 2004
R.W. Revie, ed., Uhlig's Corrosion Handbook, J. Wiley and Sons, New York, 2000
Corrosion, L.L. Shier, R.A. Jarman, G.T. Burstein, eds., Butterworth-Heinemann, Boston, 1994
E. Verink, Procedure for Constructing Pourbaix Diagrams, J. Educational Modules for Materials Science, Volume 1, No. 3, 1979

Electrochemistry

R.T. Dehoff, Thermodynamics in Materials Science, McGraw-Hill, New York, 1993
Electrochemistry and Corrosion Science, Nestor Perez, Kluwer/Springer, New York, 2004
Electrochemical Kinetics, K.J. Vetter, Academic Press. New York, 1961
Batteries and Fuel Cells, H.A. Kiehne, ed., Battery Technology Handbook, M. Dekker, New York, 2003
D. Linden and T. Reddy, eds., Handbook of Batteries, McGraw-Hill, New York, 2002
L. Blomen and M. Mugerwa , Fuel Cell Systems, Plenum Press, New York, 1993

Course Topics:

Introduction
Electrochemical Thermodynamics
Electrochemical Kinetics
Batteries and Fuel Cells
Electrochemical Corrosion
Corrosion Prevention
Environmental Effects on Mechanical Behavior
High Temperature Corrosion
Case Studies: Use of the case studies to illustrate design or corrosion-resistant systems and measurement of corrosion in situ.

Course Objectives:

Understanding of basic electrochemical reaction thermodynamics and kinetics.
Application to understanding batteries, fuel cells and sensors
Rationalization of corrosion phenomena in terms of mechanism
Introduction to corrosion measurement techniques
Use of principles to understand how corrosion can be prevented or ameliorated
Demonstration of effects of materials composition and processing in specific systems
Survey of experience on the effect of environment on mechanical failure.
Introduction to oxidation and high temperature corrosion mechanisms.
Case studies of application of corrosion principles to real situations.

Course Outcomes:

Calculation of cell potential for various electrodes, electrolytes, temperatures and pressures
Factors in the design of batteries and fuel cells for various applications
Use of Pourbaix diagrams to understand corrosion and active-passive behavior
Use of Tafel plots and Evans diagrams to predict component behavior.
Relation between immersion testing, electrochemical measurements and material performance
Assessment of alloy selection vs. coatings vs. cathodic protection vs. inhibitors to solve corrosion problems.

Assessment Tools:

Homework (3 sets)
Hour exams (2)
Term paper (one, 10-15 pages on topic of student's choosing)

Professional Component: 100 %

Prepared by: Carl Altstetter **Date:** March 2007

MSE 450—Introduction to Polymer Science and Engineering

Catalog Description: Fundamentals of polymer science and engineering. Polymer solution properties, conformation and molecular weight characterization. Rheological and viscoelastic behavior: relaxations and transitions, rubber elasticity. Crystallinity, morphology and deformation of crystalline polymers. Blends and composites. Methods of fabrication.

Prerequisites: Advanced undergraduate or graduate standing. Students in the polymer area in materials science and engineering may not receive graduate credit for this course without the permission of the instructor. *3 hours (undergraduate students), or* 3 or 4 hours (graduate students). 3 lecture hours/week.

Optional Textbooks: "Introduction to Polymers", 2nd Ed. R. J. Young and P. A. Lovell and "Polymer Science & Technology", 2nd Ed., J. R. Fried.

References:

Fundamentals of Polymer Science: An Introductory Text, 2nd ed – P. C. Painter, M. M. Coleman
Giant Molecules Here There and Everywhere…, A. Y. Grosberg and A. R. Khokhlov
Introduction to Physical Polymer Science, 3nd ed. – L. H. Sperling
Principles of Polymer Chemistry – Paul J. Flory
Viscoelastic Properties of Polymers – John Ferry
Rubberlike Elasticity: A Molecular Primer – James E. Mark
Physics of Polymers, 2nd ed. – G. R. Strobl
Polymer Chemistry: The Basic Concepts – P. C. Hiemenz
Polymer Physics – U. W. Gedde
Introduction to Polymers, 2nd ed. – R. J. Young and P. A. Lovell

Course Topics:

- polymer nomenclature
- polymerization
    - chain growth (mechanism and systems)
    - step growth (mechanism and chain size distribution)
- molecular weight distributions (definition and measurement)
- polymer solutions (Flory-Huggins model and application to polymer blends)
- polymer chain conformations
    - calculation of end-to-end distribution function W(r) for short range interaction chains
    - calculation of rms end-to-end distance <r2>
    - flexibly-jointed chain, freely rotating chain, hindered rotation chain
    - rotational isomeric state scheme and temperature dependence
    - chain with long range interactions (excluded volume effect)
    - radius of gyration
- the amorphous state of polymers
- the glass transition (configurational entropy model)
    - effect of polymer structure
    - effect of additives such as plasticizers
- polymer crystallization (measurement, unit cell, morphology and kinetics)
- mechanical properties of amorphous polymers
    - rubber elasticity (theory and experiment)
    - bulk viscosity
    - temperature dependence (WLF equation, time-temperature equivalence)
    - molecular weight dependence (reptation model)
- viscoelasticity
    - creep, stress relaxation, dynamic mechanical response
    - engineering (springs and dashpot models (Maxwell, Voigt, 4-Parameter model))
    - molecular (Rouse model)

Course Objectives: To introduce students to the science and engineering of polymers, including:

- To have students be able to read trade literature knowledgeably
- To teach students the mechanisms of polymer synthesis and its effect on configuration, molecular weight and properties.
- To derive, from a physical (statistical) model the effect of polymer solvent and polymer-polymer interactions on the phase structure.
- To teach students the effect of interactions on the conformation of a polymer molecule in solution and the melt.

To teach students the meaning and effect on properties of the glass transition (Tg).
To have the students develop an understanding of the basis for the ability of a polymer to crystallize, the resulting conformation, crystal structures and morphology. Including means of characterization thereof, and the effect on properties.
To have the students develop an understanding of the molecular basis of the mechanical properties of an amorphous polymer above and below Tg and of a semi-crystalline polymer above and below the melting point.

Course Outcomes:
Given the chemical structure of a monomer(s) and a polymerization mechanism, be able to predict the resulting configuration and potential for crystallization.
Given a mixture of 2 or more polymers of known molecular weight, be able to calculate the Mn, Mw and polydispersity of the mixture.
For a given value of c be able to predict the miscibility of a polymer and a potential solvent.
Be able to use solvent parameter tables to predict the solubility of any polymer in various solvents.
Be able to predict the size (end to end distance and radius of gyration) of a polymers molecule in a solution under various molecular constraints and interactions
Be able to describe the effect of Tg on the mechanical properties of a polymer as a function of temperature.
Be able to measure the crystallinity of a polymer and predict its effect on mechanical properties.
Be able to predict the long time behavior of a polymer on the basis of short time measurements.
Be able to calculate the restoring force of an elastomer as a function of extension.

Assessment Tools:
Homework problems assigned weekly
3 closed book, written exams.

Professional Component: 100%

Prepared by: Paul Braun **Date:** April 2007

MSE 451—Introduction to Polymer Synthesis

Catalog Description: Fundamentals of polymer synthesis and configuration characterization. Examines step-growth, addition, and coordination polymerization; kinetics and molecular weight distributions. Studies co-polymers; applications of IR, NMR, and ESCA to configuration characterization. Credit is not given for both MSE 451 and MSE 403.

Prerequisite:s Concurrent registration in MSE 450. *1 hour.* 2 lecture hours/week, 8 weeks

Textbook: Class Notes

References: Recommended if you want to buy a text
Polymer Chemistry Stevens (used for MSE 457) or Polymer Chemistry: An Introduction, Seymour and Carraher

Course Topics:
Introduction to polymers, Definitions
Condensation Polymerization
Addition Polymerization
Coordination Polymerization
Copolymers
Chemical Characterization

Course Objectives:
To complement MSE 450 for graduate students and undergraduates desiring a more complete introduction to polymer synthesis and for chemistry students wanting an introduction to polymer synthesis
To briefly introduce students to polymers if not taking MSE 450
To teach students, in greater detail than MSE 450, the mechanisms of the major types of polymer synthesis and their effect on configuration, molecular weight and properties
To teach students the effect of monomer reactivity on co-polymer configuration and composition.
To teach students the basics of means of polymer composition and configuration characterization.

Course Outcomes:
Be able to predict molecular weights from polymerization kinetics for condensation and addition polymerizations.
Understand differences in terms of polymerization mechanism and product of a) free radical versus coordination addition polymerization and b) bulk, solution, suspension and emulsion addition polymerization.
Be able to predict composition and configuration of free radical polymerized co-polymers in terms of reactivity and feed ratios and understand how to measure needed factors.
Understand the basis for mass spectrometry, ESCA, UV and visible spectroscopy, FTIR and Raman spectroscopy and NMR measurements of polymer composition and configuration.

Assessment Tools:
1. Homework problems assigned for each section
2. One, open book, written exam.

Professional Component: 100%

Prepared by: Phillip Geil **Date:** October 2006

MSE 452—Polymer Characterization Laboratory

Catalog Description: Characterizes polymer materials experimentally to investigate molecular, microstructural, and macroscopic aspects of their mechanical, thermal, electrical, and optical properties. A team project is an integral part of this course.

Prerequisites: Materials Science and Engineering 350. *4 hours.*. 1 hour lecture, 4 hours lab, 3 hours independent project/week.

Textbook: Class notes

References: Notes from MSE 350.
Collins, Bares and Billmeyer, "Experiments in Polymer Science," Wiley-Interscience, New York, 1973

Course Topics:
Polymer synthesis—free radical polymerization, copolymerization.
Characterization—dilute solution viscometry; gel permeation chromatography; infrared spectroscopy; gel electrophoresis; differential scanning calorimetry
Processing—compression molding; influence of processing on density.
Mechanical behavior—dynamic mechanical spectroscopy; time-temperature superposition.
Electronic properties—field effect transistors and light emitting diodes

Course Objectives:
To teach students a hands-on acquaintance with important modern polymer laboratory techniques of synthesis, characterization, processing, and mechanical behavior.
To teach students to analyze and interpret results of laboratory experiments; to formulate critical evaluations of both positive results (results that were as expected) and negative results (results that were not as expected).
To teach students techniques of experimental data acquisition (manual and computer-based); techniques of plotting and analysis of data; and effective communication of findings in the form of a concise laboratory report.
To teach students to design and implement in a group setting an open-ended team project to complement the predesigned aspect of this laboratory; to prepare a written and oral presentation of this project.
To teach the students some basics of polymer electronics device processing and test

Course Outcomes:
Given an unidentified polymer sample, be able to determine its thermal transition temperatures, solubility, and flammability.
Given an unidentified polymer sample, be able to determine its molecular weight, molecular weight distribution, and chemical composition.
Be able to predict the influence on mechanical and processing properties of changing the sample's molecular weight and molecular weight distribution.
Given a desired range of operating temperature, be able to predict how to select a polymer sample whose chemical makeup will give it desirable thermal relaxation properties (melting temperature, glass transition temperature) and whose molecular makeup will give it desirable processability, mechanical and electrical relaxation processes (rate dependence of relaxation functions).
Given an open-ended request to perform as a team of 2-3 students a laboratory project of unspecified content during the limited time of the semester and with the resources available to the laboratory, design and execute this project, summarize it in written form, and communicate it orally to the class.

Assessment Tools:
A laboratory report on each of the predesigned laboratory projects, written by the laboratory team of 2-3 students.
An oral and written presentation of the open-ended team project.
Pre-lab quizzes administered from time to time just before the laboratory begins.

Professional Component: 100%

Prepared by: John A. Rogers **Date:** May 2007

MSE 453—Plastics Engineering

Catalog Description: An introductory course to plastics engineering. Examines components of plastics and data banks; viscoelasticity, yield, and fracture; reinforced polymers; and forming, design (project), and current advances

Prerequisites: MSE 450. *3 hours*. 3 lecture-discussion hours/week.

Textbook:: Class notes

References: (on reserve in library, * available in office)

Birley, Haworth and Batchelor, Physics of Plastics, Hanser *
McCrum, Buckley and Bucknall, Principles of Polymer Engineering, Oxford *
Miller, Intro. to Plastics and Composites: Mechanical Properties and Eng. Applications, Dekker
Crawford, Plastics Engineering, Pergamon (Chem.) *
Progelhof and Throne, Polymer Engineering Principles, Hanser (Chem).
Richardson and Lokensgard, Industrial Plastics, 3rd Edition, Delmar Pub.,Albany, NY 1997*
Strong, Plastics: Materials and Processing, Prentice Hall, 2000, Upper Saddle River, NJ*
MSE 450 Introduction to Polymers notes, P. Geil*

Course Topics:

Review of Polymer Science and Engineering fundamentals;
Design and design examples
Material selection
- a. Data sheets
- b. Polymer families (class presentations)

Process selection
- a. Introduction
- b. Processing techniques (class presentations)

Cost modeling
Life cycle analysis, recycling
Environmental resistance
Term project presentations
Discussions of Modern Plastics, Plastics News and Plastics Engineering articles as appropriate

Course Objectives:

To review engineering aspects of polymer processing-structure-property relationships.
To describe and demonstrate methods of plastics design
To evaluate usefulness and drawbacks of plastics data sheets.
To evaluate plastics company's web sites for design data and information.
To evaluate properties, processing methods, cost, etc. of commercial plastics and plastics systems. (student presentations)
To evaluate different methods of processing plastics in terms of method, advantages and disadvantages (student presentation)
To teach students various methods of cost analysis.
To provide students with an appreciation of problems and perspectives in environmental, life cycle and recycling aspects of plastics use.
To develop an appreciation of current trends in plastics engineering
To design a product based on plastics taking into consideration (but not limited to) mechanical, thermal, environmental, cost, manufacturability, sustainability, and life cycle factors.

Course Outcomes:

Ability to evaluate company supplied information for design purposes.
Knowledge of uses and techniques of plastics processing, including limitations
Ability to "cost" plastics products, including life cycle analysis.
Recognition of means to develop life-long learning habits in the area of plastics engineering.
The appropriate design of a "plastics part"

Assessment Tools:

Oral (Power Point) presentations on
- a. a family of polymers
- b. a plastics company web site (when time permits)
- c. processing techniques
- d. design project

Two written exams, including questions submitted by the students on their oral presentations and drawn from assigned articles in Modern Plastics, Plastics News, Plastics Engineering, etc.

Student evaluations of the oral presentations before and during presentation.
Design project report

Professional Component: 100%

Prepared by: Phillip Geil **Date:** March 2007

MSE 455—Polymer Physics I, Structure and Properties

Catalog Description: Techniques and applications of polymer crystal structure and morphology observation; x-ray, electron, light and neutron scattering and diffraction; light and electron microscopy. Morphology-processing-property relationships of crystalline polymers, blends and copolymers; liquid, plastic and condis crystals; deformation mechanisms and orientation characterization; relaxations and transitions; crystallization theory

Prerequisites: MSE 450 *3 hours,* 3 lecture-discussion hours/week

Textbook: Class notes and distributed (out of print) texts.

References:

K. C. Holmes and D. M. Blow, The use of X-ray Diffraction in the Study of Protein and Nucleic Acid Structure, Interscience Reprint, New York 1966 (distributed)

B. K. Vainshtein, Diffraction of X-rays by Chain Molecules, Elsevier, Amsterdam, 1966

D. C. Bassett, "Principles of Polymer Morphology," Cambridge Univ. Press, Cambridge 1981 (distributed).

P. H. Geil, Polymer Single Crystals, Interscience-Wiley, New York, 1963 (CD distributed)

Course Topics:

Techniques of structure observation

a. microscopy: OM, SEM, TEM and SPM; resolution, sample preparation; dark field; interpretation

b. diffraction: electron, x-ray and neutron, sphere of reflection, effects of helical conformation, defects and crystal size on diffraction pattern, simulation of unit cell, crystallinity and orientation characterization, SAXD.

Polymer morphology and relationship to properties: solution crystallization of single crystals; melt crystallization of single crystals, hedrites and spherulites; effect of annealing; kinetic theory of crystallization; "morphology" of amorphous polymers; crystallization from the glassy and oriented states.

Deformation of crystalline polymers; mechanisms, morphological aspects and models; effect of annealing; effect on properties;

Relaxations and transitions; methods of measurement and relationship to molecular structure, morphology and properties

Polymer blends and co-polymers: effect of processing and composition on morphology and properties

Course Objectives:

To demonstrate the correlation between, and advantages and disadvantages of, microscopy and diffraction methods of polymer structure characterization.

To describe and demonstrate methods of sample preparation for TEM, including interpretation of micrographs thereof.

To derive, from a physical basis, scattering equations for, in order, atoms, particles, molecules (helical in particular) and unit cells.

To teach students the relationship of observed X-ray and ED patterns to reciprocal space and the sphere of reflection, including effects of crystal size and type I and II paracrystalline defects.

To provide students with a detailed, current understanding of the morphology of crystalline polymers, as crystallized from solution, melt, glass and oriented melt and of the effect of annealing.

To provide students with an appreciation of the historical development and controversies in the field of polymer morphology.

To teach students knowledge of the techniques, and limitations thereof, for characterization of degree of crystallinity and orientation.

To extend student's knowledge of methods of measurement and interpretation, in terms of molecular motions, degree of crystallinity and morphology, of polymer relaxations and transitions.

To teach students the effect of composition and processing history on morphology and properties of block copolymers and blends.

Course Outcomes:

Given a polymer sample, be able to suggest methods (and potential limitations) of sample preparation for morphology observation by TEM.

Given an oriented polymer sample, be able to suggest appropriate techniques for characterization of the orientation of the crystalline and amorphous segments therein.

Given a polymer fiber x-ray diffraction pattern, be able to determine the physical and chemical repeat distances and the unit cell parameters.

Given polymer x-ray diffraction scans, be able to calculate relative degrees of crystallinity, crystal size and defect content.

Be able to describe the effect of crystallization conditions, including degree of supercooling, orientation, and pressure, on the crystallinity, morphology and physical properties (modulus and small molecule diffusion) for representative crystallizable polymers.
Given the DMA or dielectric spectroscopy curve for a polymer, be able to suggest an interpretation in terms of transition and relaxation processes.
Given the composition of a block copolymer and method of sample preparation, be able to predict its morphology.

Assessment Tools: Homework problems involving application of the diffraction topics
A written, open book exam on the first part of the course (Topic 1) designed to test the student's ability to apply his/her knowledge.
An oral exam on Topics 2-5 based on a more extensive set of outcomes that are distributed to the students.

Professional Component: 100%

Prepared by: Phillip Geil **Date:** May 2007

MSE 457/CHEM 457—Polymer Chemistry

Catalog Description: Comprehensive overview and examination of the methods used to synthesize macromolecules. Both descriptive and mechanistic organic chemistry, as it relates to polymer synthesis, will be discussed.

Prerequisites: Senior standing in MSE or CHEM. *3 hours*. 3 lecture-discussion hours/week

Textbook: Stevens, Malcolm P. *Polymer Chemistry: an introduction*, 3rd Edition, Oxford: New York 1999

References:
Odian, G. *Principles of Polymerization*, Third ed.; Wiley: New York, 1991.
Flory, P. J. *Principles of Polymer Chemistry*, University Press: Ithaca, 1953.
Painter, P. C.; Coleman, M.M. *Fundamentals of Polymer Science*, Technomic: Lancaster, PA, 1994.
Encyclopedia of Polymer Science and Engineering, Second ed.; 1985-1990. Editors: Mark, H. F., Bikales, N. M.; Overberger, C. G. and Menges, G.

Course Topics:

1. INTRODUCTION
   a. Historical notes
   b. Survey of polymerization types and macromolecular architectures
   c. Chemical and physical differences between small molecules and macromolecules
   d. Biopolymers vs. synthetic polymers
   e. Polymers as materials: Case Study, Kevlar®, Spectra™ and Spider Silk
2. CHARACTERIZATION OF MACROMOLECULES
   a. Molecular mass and molecular mass distribution
   b. Molecular size and shape characterization
   c. Polymer composition, constitution and stereochemistry
   d. End group determination
3. ORGANIC CHEMISTRY OF SYNTHETIC HIGH POLYMERS
   a. Step-growth polymerizations
   b. Dendritic molecules and hyperbranched polymers
   c. Polymers through genetic engineering
   d. Radical addition polymerization
   e. Controlled radical polymerization
   f. Living addition polymerizations
   g. Ring-opening polymerizations
   h. Transition-metal-catalyzed polymerizations
   i. Copolymerization
   j. Macromolecular stereochemistry
4. SUPRAMOLECULAR POLYMER CHEMISTRY)
   a. Overview of supramolecular interactions
   b. Types of order in molecular materials
   c. Molecular architecture and supramolecular chemistry

Course Objectives:

1. To review those aspects of polymer characterization relevant to developing an understanding of the results of polymer synthesis.
2. To have the students develop an understanding of the relationship between the various common polymerization mechanisms and resulting products.
3. To have the students understand the relationship between configuration, as detemined by the synthesis process, and supermolecular structure.

Course Outcomes:

1. Ability to describe representative reactions for each of the polymerization mechanisms.
2. Ability to suggest (design) one or more polymerization reactions, including monomers, for desired product.
3. Ability to describe how the properties of a polymer (e.g., molecular weight, crystallinity, transparency, etc) can be varied by control of the polymerization

Assessment Tools: 3 written exams; 10 homework assignments

Professional Component: 100%

Prepared by: Paul Braun **Date:** April 2007

MSE 458/CHEM 482—Polymer Physical Chemistry

Catalog Description: Intermediate level introduction to the fundamental physical chemistry of polymer systems. Focus is on equilibrium conformation, structure, properties, and phase transitions of polymer solutions, dense melts, liquid crystals, mixtures, block copolymers, surfaces and interfaces, and electronic polymers

Prerequisites: 00-level course in thermodynamics, statistical thermodynamics or physical chemistry. *3 hours or 4 hours.* 3 lecture-discussion hours/week

Textbook: M. Rubinstein and R. H. Colby, "Polymer Physics"

References:
A.Y Grosberg and A.R.Khoklov, Statistical Physics of Macromolecules, AIP Press, New York, 1994.
P.-G. deGennes, Scaling Concepts in Polymer Physics, Cornell University Press, Ithaca, 1979.
P.J.Flory, Statistical Mechanics of Chain Molecules, Hansen Publishers, New York, 1969.
P.C.Hiemenz, Polymer Chemistry - The Basic Concepts, Marcel Dekker, New York, 1984.

Course Topics:
Polymer structure and conformational statistics; chemically realistic models versus coarse-grained descriptions.
Dilute solution conformation and solvent quality; excluded volume and chain swelling; theta state and collapse to globule in poor solvents; charged polyelectrolytes and coil-to-rod transition.
Dense solutions, melts, gels and rubber networks; dilute, semidilute, concentrated and melt regimes; scaling concepts; gelation and pecolation concepts; classical theory of rubber elasticity.
Polymers near and tethered to surfaces, and in confined spaces; conformation and film thickness; physical adsoprtion; grafted polymer brushes, colloidal stability.
Liquid crystalline phases; mesogenic molecules; nematic and smectic order; role of different intermolecular forces; Onsager theory of lyotropic rigid rods; thermotropics; semiflexibility effects on phase diagrams.
Liquid-liquid phase separation; mixture thermodynamics and regular solution theory; Flory-Huggins theory of polymer solutions and blends; interface widths in phase-separated morphologies.
Self-assembly and microphase separation; copolymer molecular structure; order-disorder phase transition, ordered phase symmetries, domain sizes; micelle formation in selective solvents.
Conjugated and conducting polymers; electron delocalization, optical properties, doping, electrical conductivity and transport mechanisms.

Course Objectives:
To fundamentally understand and derive the connection between monomer structure, temperature, solution conditions, degree of polymerization and 3-dimensional conformation.
To understand and derive how charging polymers can result in fundamental property changes.
To understand and derive the physical basis for thermodynamic, conformational and structural changes in polymers solutions and melts.
To understand the physical origin of rubber elasticity and gelation.
To understand the conformation of polymers adsorbed on surfaces, and trapped between surfaces, and the influence of solvent quality and polymer-surface attractive interactions.
To learn about liquid crystalline phases, their symmetry characterization, and the physical forces which control phase diagrams.
To learn about phase separation in polymer solutions and blends, and the basic theoretical understanding.
To learn about microphase separated copolymer structures, the structure of phase separated blends, and the influence of thermodynamics and molecular weight on these questions.
To introduce the student to electroactive polymers, and the conformational, optical, and electrical properties in synthetic metals.

Course Outcomes:
To understand the diverse equilibrium experimental behavior of polymers in the solution, melt, rubbery, and confined state.
To be able to qualitatively think at the molecular level about physical polymer behavior and processes.
To be able to quantify with simple physical ideas(statistical thermodynamic) the competing entropic and enthalpic aspects of a multitude of physical processes.
To expose the student to both classical, and modern, theoretical concepts in physical polymer science and how they can be used to make experimentally testable predictions.
To provide the fundamental equilibrium foundation for learning about polymer dynamics and rheology.

Assessment Tools: Homework problems involving application, and extension, of concepts and calculational methods presented in class.

Written open book midterm and (comprehensive) final exams.
For 4 hours credit, a ~10 page term paper on a subject in physical polymer science of interest to the student and relevance to the class subject matter.

Professional Component: 100%

Prepared by: Kenneth Schweizer **Date:** March 2007

ECE 440—Solid State Electronic Devices

Catalog Description: Semiconductor materials and their electronic properties and applications to electronic devices; p-n junctions; transistors; junction field effect transistors and MOS devices; and introduction to integrated circuits. Credit is not given toward graduate degrees in Electrical and Computer Engineering

Prerequisites: Physics 214 - University Physics, Quantum Physics; credit or concurrent registration in ECE 229 - Introduction to Electromagnetic Fields. 3 hours. Lecture: 3 hr/week.

Textbook(s): Ben G. Streetman , *Solid State Electronic Devices,* 5th ed., Prentice Hall

Course Topics:

Crystal structure, orientations and planes of semiconductors (1 hr)
Carriers, carrier distribution, carrier generation and recombination and energy bands (11 hrs)
Carrier transport -- drift and diffusion (6 hrs)
p-n junction, contact potential, carrier injection and diode equation (5 hrs)
Breakdown and capacitance of p-n junction (2 hrs)
Metal-semiconductor contact, Schottky barrier diode and heterojunction (2 hrs)
Junction field effect transistor, metal-on-semiconductor (MOS) capacitor and MOSFET (10 hrs)
Bipolar junction transistor (3 hrs)
Optoelectronic devices - -photodetector, light emitting diode and laser (2 hrs)

Course Objectives: The purpose of this course is to provide the student with the essential background on semiconductor materials and a basic understanding of the following semiconductor electronic devices that will be required for a successful career in electrical engineering: p-n junctions, Schottky barrier diodes, bipolar junction transistors, field effect transistors and optoelectronic devices.

These topics are important to the professional electrical or computer engineer because these devices are utilized in almost every area of electrical or computer engineering. The material in this course will provide the background that will give the student the ability to learn and understand the performance and limits of improved devices that will be required throughout the career as an electrical or computer engineer. (1, 4)

Course Outcomes: A student completing this course should at a minimum be able to:

Identify crystalline planes and directions in a crystal lattice in terms of Miller Indices.
Calculate the intrinsic carrier concentration in semiconductors, and apply the concept of compensation and space charge neutrality to calculate the electron and hole concentrations in extrinsic semiconductor samples.
Compute the electron and hole concentrations if the Fermi or quasi-Fermi level is given; determine the Fermi or quasi-Fermi level in a semiconductor if the carrier concentration is given.
Calculate the recombination characteristics and excess carrier concentrations as a function of time for low-level injection conditions in a semiconductor.
Determine the drift and diffusion components of electron and hole currents.
Calculate the contact potential and the maximum electrical field in a p-n junction in equilibrium.
Calculate the excess carrier concentrations at the boundaries between the space-charge region and the neutral n- and p-type regions of a p-n junction for either forward or reverse bias.
Distinguish between the current conduction mechanisms and calculate the minority and majority carrier currents in a forward or reverse biased p-n junction diode.
Predict whether a metal-semiconductor contact will be a rectifying contact or an ohmic contact based on the metal work function and the semiconductor electron affinity and doping.
Estimate the drain current of a JFET below and above pinch-off.
Calculate the threshold voltage of a non-ideal MOS transistor, and estimate the drain current of an MOS transistor above threshold for low drain voltage and at pinch-off.
Calculate the terminal parameters of a BJT in terms of the material properties and device structure.

Assessment Tools: Exams and homework assignments.

Professional Component: 100%

Prepared by: K.C. Hsieh **Date:** March 2001

MSE 460—Electronic Materials and Processing I: Semiconductors and Semiconductor Processing

Catalog Description: Introduces senior engineers and new graduate students to the materials science, engineering, and processing of semiconductors. The structure and chemistry of semiconductors are related to the electronic and optical properties. Includes: how semiconductors are produced and how to control processing to achieve desired materials properties; how to design and produce novel materials to obtain superior performance from electronic devices.

Prerequisites: Senior standing in Materials Science and Engineering. Strongly recommended: MSE 304, PHYCS 460 or equivalent and ECE 440 or equivalent. *3 hours*, 3 lecture hours/week.

Textbook: Angus A Rockett, "The Materials Science of Semiconductors", Kluwer, in final editing for publication, and course notes.

References:
M.A. Herman and H. Sitter, Molecular Beam Epitaxy Fundamentals and Current Status (Springer-Verlag).
J.Y. Tsao, Materials Fundamentals of Molecular Beam Epitaxy.
Linda M. Miller and James J. Coleman, "Metalorganic Chemical Vapor Deposition", CRC Critical Reviews.
J.W. Matthews, Epitaxial Growth, Part B (Academic).
A.W. Adamson, Physical Chemistry of Surfaces (John Wiley).
Ben G. Streetman, Solid State Electronic Devices (Prentice-Hall).
Keshra Sangwal, Etching of Crystals (North Holland).
S.M. Sze, VLSI Technology (McGraw-Hill).
R.A. Levy, Microelectronic Materials and Processes (Kluwer).
R.E. Hummel, Electronic Properties of Materials (Springer-Verlag).

Course Topics:
Overview of the Physics of Solids
- a. Crystallography and diffraction in electronic materials
- b. Energy band structures, capacitance, conductivity.

Overview of Diodes, Schottky Barriers, and Heterojunctions
Semiconductor Crystal Growth (Basic mechanisms of growth, Czochralsky method, molecular beam epitaxy, chemical vapor deposition)
Physics of Semiconductors (Band theory, semiconductor design based on bond chemistry, semiconductor alloy design, amorphous semiconductors, defects in semiconductors and their engineering)
Amorphous semiconductors
Organic Light Emitting Materials

Course Objectives:
To provide an in-depth description of the materials science that underlies the semiconductors in microelectronic devices. (In particular, structure-processing-properties relationships.)
To describe and provide a fundamental understanding of techniques for design and engineering of semiconductors for microelectronics.
To teach students the physical processes which underlie the optoelectronic behavior of semiconductors.
To teach students the three primary methods of growing crystals in microelectronics with emphasis on the relationship of process parameters to the materials properties that result.
To illustrate the application of basic materials science to electronic materials design (alloy theory and phase diagrams, point and extended defects in materials and their thermodynamics, process kinetics, polymer science.
To challenge students with open ended design questions integrating the course material with materials from previous classes.

Course Outcomes:
Given a hypothetical or real problem with an electronic materials device or process, explain the cause of the problem and propose solutions to the problem.
Prepare a high quality term paper on a subject of relevance to electronic materials and processing.
Explain, based on the energy/momentum diagrams for a solid or the atomic orbital energies, the nature of a semiconductor (bonding character, optoelectronic properties, band edge offsets, etc) or the nature of expected defects in the material (level depth, hydrogenic or deep level character).
Recommend processes or conditions for a given process for fabrication of semiconductors.

Given the performance of an electronic device, diagnose problems and predict the nature of the defects giving rise to these. Recommend methods for improvement.
Understand the design of organic light emitting and conductive polymers and the engineering of contacts and luminescent die materials.

Assessment Tools: Homework problems involving open-ended questions and design problems.
Three closed book exams designed to test the student's ability to apply his/her knowledge.
A term paper graded on effectiveness, content, organization, and English composition.
An oral summary of the term paper and answers to questions from the class.
Team learning approach. Students work with partners on homeworks and term paper.

Professional Component: 100%

Prepared by: Angus Rockett **Date:** May 2007

MSE 461—Electronic Materials and Processing II: Non-semiconductor materials and processing

Catalog Description: Introduction to the materials science, engineering, and processing of microelectronic materials including especially conductors and dielectrics. The course makes use of the concepts developed in materials science to understand why certain materials make acceptable contacts and dielectrics while others do not. Demonstrates how manufacturing problems can be overcome with careful materials design and processing. Examines some of the processing techniques commonly used in microelectronic circuit manufacture during metallization, dielectric formation and lithography.

Prerequisites: Senior or graduate standing in MSE. *3 hours,* 3 lecture-discussion hours/week

Textbook: James W. Mayer and S.S. Lau,"Electronic Materials Science for Integrated Circuits in Si and GaAs," MacMillan and course notes.

References:

Shyam P. Murarka and Martin C. Peckerar, Electronic Materials Science and Technology, Academic Press, 1989.
Shyam P. Murarka, Silicides for VLSI Applications, Academic Press, 1983.
Ben G. Streetman, Solid State Electronic Devices (Prentice-Hall).
Keshra Sangwal, Etching of Crystals (North Holland).
S.M. Sze, VLSI Technology (McGraw-Hill).
R.A. Levy, Microelectronic Materials and Processes (Kluwer).
R.E. Hummel, Electronic Properties of Materials (Springer-Verlag).

Course Topics:

Conductors for Integrated Circuits (simple metals, metal alloys, electromigration resistant materials, compounds, silicide nucleation and reaction kinetics, interface stability criteria, transparent conductors)
Sputter Deposition of Thin Films
Dielectrics for Integrated Circuits (Silicon dioxide, oxidation kinetics, process additives and how they influence properties, nitrides, plasma-enhanced deposition, high k materials, low k materials)
Chemical mechanical polishing
Rapid thermal processing
Introduction to lithography
Photoresists (single and multicomponent, dyes, contrast enhancers, photoactivated compounds, dissolution inhibitors)
Reactive Ion Etching

Course Objectives:

To provide an in-depth description of the materials science that underlies the non-semiconductor materials in microelectronic devices. (In particular, interfacial stabilities, process chemistries, and reaction kinetics)
To describe and provide a fundamental understanding of techniques for design and engineering of non-semiconductor materials for microelectronics.
To teach students methods for design of metals and dielectrics for nanoscale electronic applications
To teach students the two primary methods of processing materials in microelectronics (sputtering and reactive ion etching)
To illustrate the application of basic materials science to electronic materials design (alloy theory and phase diagrams, point and extended defects in materials and their thermodynamics, process kinetics, polymer science.)
To challenge students with open ended design questions integrating the course material with materials from previous classes.

Course Outcomes:

Given a hypothetical or real problem with an electronic materials device or process, explain the cause of the problem and propose solutions to the problem.
Prepare a high quality team-oriented project on a subject of relevance to electronic materials and processing. This project requires the team to make a recommendation to a "Vice President for Technology" at a hypothetical microelectronics company concerning a decision among current technology options. The team prepares the project together, is self-organized, presents a team overview of a poster orally and provides a team-written report on the recommendation.
Understand how materials interact at the nanoscale, what makes an interface stable, and how to design for stability.

Recommend processes or conditions for a given process for fabrication of semiconductors.
Given the performance of an electronic device, diagnose problems and predict the nature of the defects giving rise to these. Recommend methods for improvement.
Understand the design of advanced multicomponent photoresists.

Assessment Tools: Homework problems involving open-ended questions and design problems.
Three closed book exams designed to test the student's ability to apply his/her knowledge.
A term project graded on effectiveness, content, organization, and English composition.
An oral summary of the team project poster and answers to questions from the class.
Team learning approach. The project teams are evaluated on their effectiveness as a team and their interactions.

Professional Component: 100%

Prepared by: Angus Rockett **Date:** May 2007

MSE 462—Electronic Materials Laboratory

Catalog Description: Introduces seniors and new graduate students to the instrumentation, characterization, and experimental analysis and properties of thin film materials through a combination of lectures and experiments. Covers both the principles and practice of: (a) deposition of thin film materials by vacuum evaporation, sputtering and plasma assisted processes: (b) modification of properties by thermal reaction, surface treatment, etc., and (c) characterization of key properties including electrical conductivity, optical properties, and stress. Methods to optimize the film microstructure and engineering properties via growth techniques are emphasized.

Prerequisites: MSE 460 or 461 3 hours

Textbook: Class notes.

References:
J. L. Vessel and W. Ken, "Thin film processes", Academic Press
Milton Ohring, "The Materials Science of Thin Films", Academic Press (1992)
J. R. Taylor, “Error Analysis”, University Science Books, Sausalito, CA (1982)

Course Topics:
Introduction: thin films and vacuum
Deposition principles and processes: formation from the vapor state, thermal evaporation, sputtering, PA-CVD 4
Thermal Reactions: annealing, oxidation
Properties: microstructure, stress, hardness, optical, electrical, magnetic

Course Objectives:
To teach students the relationship between microstructure and electronic properties.
To demonstrate the role of mechanical stress in the reliability issues for microelectronics thin film systems.
To teach students the advantages of the use of correct experimental design in order to circumvent inaccuracies introduced by typical real instrumentation including correction of offsets and thermal voltages.
To provide students with the hands-on opportunity to grow thin films under high vacuum environment.
To describe typical processing issues for thin film deposition and annealing steps.
To provide students with an opportunity to design their own materials solutions for a given set of device constraints.
To teach students role of calibration techniques and steps for defining sensitivity and accuracy criterion for instrumentation.

Course Outcomes:
Given a thin film of metal on a Si wafer suggest ways of measuring strain and stress of the thin film during thermal annealing.
Given an unknown semiconductor be able to determine the carrier concentration and mobility using Hall Effect measurements.
Given a thin film sample determine the sheet resistance and contact resistance of the system.
Given an evaporation system determine the degree of spatial uniformity of the thin film using geometrical considerations.
Show how a thin-film system can exhibit both elastic and plastic deformation characteristics over an extended temperature range.
Given thermocouple system demonstrate the role of the junction properties on the accuracy of the measurement.

Assessment Tools:
Three reports with properly formatted and annotated figures and tables.
Three oral exams on each of the experiment modules..

Professional Component: 100%

Prepared by: Leslie Allen **Date:** May 2007

MSE 470—Design and Application of Biomaterials

Catalog description:	Provides an introduction to the characterization and use of biomaterials in medical applications. Presents concepts of biocompatibility in terms of structure and properties of materials and interactions between materials and proteins, cells, and tissue. Credit is not given for both MSE 470 and MSE 471
Prerequisites:	MSE 403; credit or concurrent registration in MCB 252. *3 hours*. 3 hours lecture-discussion.
Textbook(s):	"Biomaterials Science: An introduction to Materials in Medicine. Second Edition. Edited by Buddy Ratner and others."
Course topics:	Introduction: Biomaterials Cell-Biomaterials Biopolymers-1: Introduction Biopolymers-2: preparation Biopolymers-3: Hydrogel and Smart system Bioconjugation techniques Drug Delivery using biomaterials –small molecule delivery Drug Delivery using biomaterials –gene delivery Drug Delivery using biomaterials –protein delivery Biocompatibility In vivo degradation of materials Hard biomaterials Medical device design and implant Evaluation of biomaterials Micro- and nano- biomaterials In vitro and in vivo imaging and diagnosis Biomaterial in tissue engineering
Course objectives:	This course is intended to provide the student an understanding of the fundamental principles and language associated with current biomaterials research and to understand the issues associated with medical applications of these materials.
Course outcomes:	I expect the students to understand the fundamental principles and language associated with current biomaterials and the connection of biomaterials design with their function, properties, biocompatibility and biomedical applications.
Assessment tools:	Three tests and one final exam will be given. One final presentation is required.
Professional component:	100%
	Prepared by: Jianjun Cheng **Date:** June 2007

MSE 472—Biomaterials Laboratory

Catalog description: Explore various areas in biomaterials science and learn the fundamental disciplines, build lab skills, and enhance analytical thinking through experiments, demonstrations and scientific writing.

Prerequisites: Credit or registration in MSE 470. *3 hours*.

Textbook(s): Biomaterials Science: An Introduction to Materials in Medicine (Edited by Ratner et al, 2nd Edition) (A lab manual will be put together for next year.)

Other resources: Recent review papers on select topics from major journals

Course topics: Experiments are organized into modules and each module has a central theme. Modules include:
Drug Delivery: Controlled release of encapsulated protein from biodegradable microspheres
Biocompatibility Testing: Cytotoxicity assay of various materials using *in vitro* cell cultures
Natural Biomaterials: Purification and characterization of collagen from bovine calf skin
Tissue Engineering: Organotypic culture of skin tissue
Bioceramics: Fabrication of porous and biodegradable polymer-hydroxyapatite composite

Course objectives: Achieve deeper understanding of the concepts and fundamental principles in biomaterials science; learn lab skills in materials science, chemistry, physics, biochemistry, and cell biology; learn to analyze and solve problems; learn to report experimental results in scientific writing.

Course outcomes: The objectives are mostly achieved. Students from the past semesters have performed experiments successfully, and their lab reports have shown good grasp of the concepts and approaches of the experiments, rational interpretation of the results, and thoughtfulness in discussion.

Assessment tools: A mid-term exam, a final exam, a lab report for each module, and inspection of the student's lab notebook.

Professional component: 100%

Prepared by: Wujing Xian **Date:** April 2007

MSE 473—Biomolecular Materials Science

Catalog Description: This one-semester class will cover the chemical and physical foundations of biomolecular materials science. The course will consist of a series of modules on the structures and functions of basic classes of biological molecules, including lipid membranes, nucleic acids, proteins, and sugars. In a series of examples, we will study how biological and biomimetic systems self-assemble into their functional forms, and how these structures impart biological activity, by examining the specific and non-specific interactions between them over a wide range of length-scales. We will end the class with a final project, which will be a case study of your choice

Prerequisites: None. *3 hours*. 3 lecture-discussion hours/week.

Textbook: None. (Course will be based entirely on lectures.)

Course Topics:

Basic classes of biomolecular materials:
Nucleic acids
- Structure & function of DNA and RNA
- Sequencing technologies
- Biology and mechanics of DNA bending
- Physical description of semiflexible polymers

Proteins
- Hierarchical organization
- Physical basis of secondary structures
- Examples of relationship between structure and function
- How to estimate persistence of lengths

Lipids & membranes
- Fluid membranes
- Gel phase membranes
- Helfrich elasticity of membranes

Interactions between biomolecular materials: specific & non-specific
Van der Waals interactions
- Monopole-dipole interactions
- Dipole-dipole interactions
- Dipole-induced dipole interactions
- Shape dependence of van der Waals interactions

Electrostatic interactions
- Screening and dielectric constant
- Osmotic effects
- Poisson Boltzmann formalism
- Physical origins of electrostatics in water

Structural (solvation, steric, hydration) interactions
Role of water
- Structure & dynamics of water

Hydrogen bonding & hydrophobic interactions
- Physical origin of hydrophobic interactions

Polymer-mediated and colloid mediated interactions
- Depletion interactions

Specific & non-specific adhesion and binding: fusion, clustering, phase separation, complementary interactions, lock-and-key, biological 'recognition' processes

Course Objectives:

To review physics and chemistry necessary for an understanding of biomaterials.
To teach students the basic interactions governing biology from the nanoscale to the mesoscale.
To teach students the basic materials science of the membrane.
To teach students the basic materials science of nucleic acids.
To teach students the basic materials science of proteins.
Give students an opportunity to give oral presentations in the standard format of contributed talks at research meetings.
Give students an opportunity for teamwork in research
Give students practice in basic expository technical writing.

Course Outcomes: Given a type of material, be able to make educated guesses about its bonding scheme, and estimate its Young's modulus.
Be able to describe its physical origin of different types of bonds, as well as estimate its strength.
Be able to solve simple elasticity problems with semiflexible polymers such as DNA and protein filaments.
Be able to solve simple elasticity problems with fluid membranes.
Be able to make simple scaling arguments in order to make simple estimates (such as bending modulus, persistence length, radius of gyration for polymers) on new materials systems.
Be able to describe qualitatively the ways in which electrostatic interactions are altered in water, based on Poisson Boltzmann formalism.
Be able to describe qualitatively hydrogen bonding and the hydrophobic effect

Assessment Tools:

Homework	40%
Midterm	30%
Final project & presentation	30%

Professional Component: 100%

Prepared by: G.C.L. Wong **Date:** May, 2007

MSE 480/CHEM 488—Surfaces and Colloids

Catalog Description: Introduction to the chemistry and physics of surfaces and interfaces, with emphasis on behavior in liquid media; major areas include surface composition, surface and interfacial forces, colloidal stability and flocculation, and amphiphilic molecules

Prerequisite: MSE 301, CHEM 342, or PHYCS 361; or equivalent undergraduate course in thermodynamics or physical chemistry. *3 hours*.. 3 lecture-discussion hours/week

Textbook: Class notes.

References: "Principles of Colloid and Surface Chemistry," 3rd Ed., Hiemenz and Rajagopalan, Marcel Dekker, 1997.
"Intermolecular and Surface Forces," 2nd Ed., J. N. Israelachvili, Academic Press, 1991.
Electronic Teaching Aids/Computer Usage: as needed in homework problems

Course Topics:
Basic concepts of surfaces
general principles; surface structure; surface thermodynamics; curvature; adsorption.
Forces between surfaces
use of colloids; varieties of interparticle forces; van der Waals forces; electrostatic forces; zeta potential; examples.
Forces due to liquid structure
Polymers; structured liquids (small molecules); tribology and adhesion.
Forward look
summary and review; diffusion, viscoelasticity; frontier areas.

Course Objectives:
To teach a firm foundation of the materials science and engineering that underlies the field of surfaces and colloids, with emphasis on developing intuition and problem-solving techniques.
To teach students to analyze and interpret the common themes that underly seemingly disparate phenomena; to recognize and understand the unifying themes in different areas of applications.
To develop the expertise to know where to look to find out more about any of the areas that were treated in this class.
To teach students to implement an independent semester-long research and assessment project.

Course Outcomes:
A general understanding of surface energy, adsorption, relaxation, and reconstruction and their different characteristic behavior as between the general classes of materials (atomic and molecular).
A general understanding of the main types of surface forces (van der Waals, electrostatic, steric, forces owing to liquid structure) and the reasons that these forces exist.
Ability to read the literature critically in the field of surfaces and colloids, to develop informed opinions about this, and to express these opinions and reasons for them persuasively in the form of an extended term paper and homework open-ended essay problems.
Given an engineering situation, the ability to develop an informed approach to methods by which to manipulate the magnitudes and ranges of the interaction forces.

Assessment Tools: Two hour-long examinations, the second one cumulative for the entire semester.
A written presentation of an open-ended term paper on a subject of the student's choosing.

Professional Component: 100%

Prepared by: Steve Granick **Date**: May 2007

MSE 481—Electron Microscopy and Diffraction Theory

Catalog Description: Theory and application of transmission electron microscopy and diffraction with emphasis on thin crystals; electron optics, interference phenomena, interpretation of images and diffraction patterns, specimen preparation, etc.

Prerequisites: MSE 305 or equivalent. *Credit: 3 hours*. 3 lecture/discussion hours per week.

Textbook: D. B. Williams and C. B. Carter, "Transmission Electron Microscopy," Books 1 to 4, Plenum Press (1996)
Class notes and handouts

References: A number of references are used

Course Topics:

1. **Basics of electron microscopy:** Introduction to SEM and TEM; Scattering and diffraction; Elastic scattering; Inelastic scattering and beam damage; Electron sources; Optics; Lenses, apertures and resolution; The instrument and electron optics; Specimen preparation
2. **Diffraction: Diffraction patterns**: Thinking in reciprocal space; Diffraction from crystals; Diffraction from small volumes; Stereograms, planar and directional for general symmetry; Indexing diffraction patterns, the general method; Kikuchi diffraction; Obtaining CBED patterns; Using convergent beam techniques
3. **Imaging:** Imaging in the TEM; Thickness and bending effects; Dark field and weak beam techniques
4. **Microchemical analysis by energy dispersive spectroscopy:** X-ray spectrometry; The EDS-TEM interface; Qualitative X-ray analysis

Course Objectives:

To understand the principles of optics, the different types of glass lenses and how they work, and how they can be combined to form real and virtual images.
To understand the physics of different types of scattering events, viz., elastic, plastic, coherent, incoherent, forward and back scattering.
Review the dual (particle and wave) nature of electrons.
Review the principles of crystallography and systematic extinctions.
To understand how an electromagnetic lens works, the coupling of electromagnetic lenses, and effect of lens defects.
The construction of an SEM, TEM and STEM, including the function and positioning of apertures, stigmators, deflectors and detectors.
Know how to prepare thin TEM specimens of metals, ceramics, polymers and combinations of them (composites), using standard techniques.
To be able to take bright field, dark field, centered dark field and weak beam images, while correcting for astigmatism.
To be able to take a selected area diffraction pattern (SAD), convergent beam (CBED), Kossel-Möllenstedt patterns, as well as Kikuchi patterns, and use the latter as guides for orientation in reciprocal space.
To have some familiarity with the techniques of electron backscattered diffraction patterns (EBPD's) or orientation imaging microscopy (OIM) in SEM.
To plot and manipulate both planar and directional stereograms, and use them to both predict, as well as to analyze, SAD or Kikuchi patterns for any crystal system (including non-orthogonal systems such as monoclinic and triclinic).
To know the method of microchemical analyses by energy dispersive X-ray spectroscopy (EDS) and wavelength dispersive spectroscopy (WDS). Students should be familiar with both the standard (K-factor ratio) and standardless methods for quantitative evaluation of elements present in a specimen.

Course Outcomes:

an understanding of image formation by glass and electromagnetic lenses.
an understanding of the physics of scattering
an understanding of the construction of various types of electron microscopes, the function of the various parts and methods of image formation.
an understanding of methods of sample preparation for SEM and TEM.
ability to index electron diffraction patterns and interpret Kossel- Möllenstedt and Kikuchi patterns.
ability to utilize EDS and WDS results for microchemical analysis.

Assessment Tools:

Seven sets of homework problems were formulated by the instructor, complemented by teams of 3-4 students each. The students prepared questions on any topic covered or any topic that could receive more attention for the sake of clarity. The final questions were prepared in consultation with each team by the instructor. The students graded each homework assignment, and explained the solution and common mistakes before the class.
Subsequent, more involved and challenging homework projects were prepared by the instructor.
One 1 and 1/2 to 2 hour mid-term exam and a 3-hour final exam.
One project (sometimes written, always oral, sometimes a poster) was done by each student. The project was relevant to the undergraduate student's interest or to the graduate student's research topic.

Professional Component: 100%

Prepared by: Waltraud Kriven **Date:** March 2001

MSE 484—Composite Materials

Catalog Description: Introduction to metal, ceramic, and polymer-matrix composites, with an emphasis on understanding the interrelationships among processing, microstructure and properties. The basis for selecting these systems for different engineering applications are considered.

Prerequisites: Senior standing in Engineering. 3 *hours.* To receive 1 unit credit a comprehensive term paper is required. 3 lecture-discussion hours/week

Textbook: Lecture Notes.

Recommended Text: Composite Materials: Engineering and Science
F. L. Matthews and R. D. Rawlings, Chapman & Hall 1994

Course Topics:
Introduction
Reinforcements: Fibers; Strengths of Fibers
Composite Interfaces: Bonding Mechanisms; Bond Strength; Interfacial Toughness
Polymer Matrix Composites: Polymer Matrices; Processing Techniques; Glass Reinforced Plastics; Carbon Fiber Composites
Metal Matrix Composites: Metal Matrices; Processing Techniques; Interfacial Controls; Discontinuously Reinforced Composites; Fiber Composites
Ceramic Matrix Composites: Ceramic Matrices; Processing Techniques; Alumina Matrix Composites; Glass Matrix Composites
Composite Properties: Elastic Properties; Composite Strengths

Course Objectives:
To describe synthesis, processing and properties of fibers for composite reinforcements.
To examine bonding and properties of composite interfaces
To provide guidelines for selection of the matrix materials.
To describe key processing techniques for producing metal-, ceramic-, and polymer-matrix composites.
To demonstrate the relationship among synthesis, processing, and properties in composite materials
To analyze the mechanics of the composite materials.
To provide theoretical treatment of the composite properties.

Course Outcomes:
Able to explain how common fibers are produced and how the properties of the fibers are related to the internal structure.
Able to explain how interfacial bonding may be achieved between two materials.
Able to suggest and analyze the methods for determining mechanical properties of interfaces.
Able to select matrices for composite materials in different applications.
Able to describe key processing methods for fabricating composites.
Able to explain how key processing parameters affect composite properties.
Able to analyze the mechanics of the composite materials.
Able to explain the anisotropy in the elastic properties and strengths of the composite.

Assessment Tools:
Weekly homework problems
Two midterm examinations
3. Final examination.

Professional Component: 100%

Prepared by: Jian-ku Shang **Date:** April 2007

MSE 485/CSE 485/Phys 466—Atomic-Scale Simulations

Catalog Description: To learn and apply some of the fundamental techniques of Monte Carlo and Molecular Dynamics used in (primarily classical) simulations in order to help understand and predict properties of microscopic systems in materials science, physics, chemistry, and biology. Numerical algorithms, connections between simulation results and real properties of materials (structural or thermodynamic), as well as statistical and systematic error estimation using real simulation programs will be emphasized. A simulation project composed of scientific research, algorithm development, and presentation is required

Prerequisites: A course in statistical mechanics, or statistical thermodynamics, and prior experience in programming in C, C++, or Fortran. *3 hour*. 3 lecture hours/week

Textbook: "Understanding Molecular Simulations" by Frenkel and Smit

Supplementary Text: Computer Simulation of Liquids, M.P. Allen and D.J. Tildesley (Oxford Univ. Press) 1997

Course Objectives: Important areas of emphasis will be connections between the simulation results and real properties of materials (structural or thermodynamic quantities), as well as numerical algorithms and systematic and statistical error estimations. Methods and applications include:

Introduction to concepts, use, limitations, and applications of Molecular Dynamics, including integration algorithms, static and dynamic correlations functions and their connection to order and transport.
Introduction to concepts, use, limitations, and applications of Monte Carlo and Random Walks, including variance reduction, random number generation, and Metropolis algorithms.
Introduction to concepts, use, limitations, and applications of Kinetic Monte Carlo, heat diffusion, Brownian motion, etc.
Simulations of Phase Transitions (melting-freezing, calculating free energies)
Simulations of Polymers (growth and equilibrium structure)
Quantum Simulation Zero temperature and finite temperature methods.
Optimization techniques, such as simulated annealing, genetic algortithms.
(Choice of Kinetic Monte Carlo or Quantum Monte Carlo is by instructor.)

Course Outcomes: Familiarity with the basic concepts, use, and limitations of Molecular Dynamics and Monte Carlo methods for simulation of materials properties through both theoretical development and personal application of methods.
Introduced to and application of concepts of random number generation, statistical and systematic error estimation, and variance reduction.
Application of methods to phase transitions, polymer growth, and kinetic MC, and familiarity with difficulties and limitations of methods for such.
Introduced to optimization ideas and techniques via simplistic homework simulation.

Assessment Tools: Homework problems (including computer simulation using Engineering WorkStations) involving fundamental knowledge and application of each topic.
Submit and orally defend proposed group project due at end of semester.
Written mid-term examination on fundamentals of subset of topics.
Final Group Project, in lieu of Final Exam, designed to test the student's understanding of concepts and their ability to apply his/her knowledge. Project is graded on any pertinent algorithmic and scientific content and on both oral and electronic report presentations.

Professional Component: 100%

Prepared by: Duane D. Johnson **Date:** March 2001