

# Mechanical Engineering & Materials Science

Website: <https://mems.wustl.edu/academics/graduate/index.html>

## Courses

Visit online course listings to view semester offerings for E37 MEMS (<https://courses.wustl.edu/CourseInfo.aspx?sch=E&dept=E37&crslvl=5:8>).

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### E37 MEMS 500 Independent Study

Independent investigation on topic of special interest. Prerequisites: graduate standing and permission of the department chair. Students must complete the Independent Study Approval Form available in the department office.

Credit variable, maximum 3 units.

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### E37 MEMS 5001 Optimization Methods in Engineering

Analytical methods in design. Topics include: mathematical methods, linear and nonlinear programming, optimality criteria, fully stressed techniques for the design of structures and machine components, topological optimization, search techniques and genetic algorithms. Knowledge of calculus and computer programming is expected.

Credit 3 units. EN: BME T, TU

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### E37 MEMS 501 Graduate Seminar

This is a required pass/fail course for master's and doctoral degrees. A passing grade is required for each semester of full-time enrollment. A passing grade is received by attendance at the weekly seminars.

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### E37 MEMS 5102 Materials Selection in Design

Analysis of the scientific bases of material behavior in the light of research contributions of the past 20 years. Development of a rational approach to the selection of materials to meet a wide range of design requirements for conventional and advanced applications. Although emphasis is placed on mechanical properties, acoustical, optical, thermal and other properties of interest in design are discussed.

Credit 3 units. EN: BME T, TU

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### E37 MEMS 5104 CAE-Driven Mechanical Design

An introduction to the use of computer-aided engineering (CAE) tools in the mechanical design process. Topics include: integrating engineering analysis throughout the process; multidisciplinary optimization; and computer-aided design directed toward new manufacturing processes. Students will work with commercial and research software systems to complete several projects. Students should have experience and familiarity with a CAD tool, optimization and the finite element method. Prerequisite: MEMS 202 Computer-Aided Design or equivalent.

Credit 3 units. EN: BME T, TU

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### E37 MEMS 5301 Nonlinear Vibrations

In this course, students are introduced to concepts in nonlinear dynamics and vibration and application of these concepts to nonlinear engineering problems. Specific topics include: modeling of lumped and continuous nonlinear systems (strings, beams and plates); vibrations

of buckled structures; perturbation and other approximate analytical methods; the use and limitations of local linearization; properties of nonlinear behavior, such as dimension and Lyapunov exponents; stability of limit cycles; bifurcations; chaos and chaotic vibrations; experimental methods and data analysis for nonlinear systems.

Concepts are reinforced with a number of examples from recently published research. Applications include aeroelastic flutter, impact dynamics, machine-tool vibrations, cardiac arrhythmias and control of chaotic behavior.

Credit 3 units. EN: BME T, TU

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### E37 MEMS 5302 Theory of Vibrations

Analytical methods in vibrations. Topics include: Duhamel's integral, Laplace and Fourier transforms and Fourier series with applications to transient response, forced response and vibration isolation; Lagrange's equations for linear systems, discrete systems, degrees of freedom, reducible coordinates, holonomic constraints and virtual work; matrix methods and state variable approach with applications to frequencies and modes, stability and dynamic response in terms of real and complex modal expansions, dynamic response of continuous systems by theory of partial differential equations, Rayleigh-Ritz and Galerkin energy methods, finite difference and finite element algorithms.

Credit 3 units. EN: BME T, TU

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### E37 MEMS 5401 General Thermodynamics

General foundations of thermodynamics valid for small and large systems, and for equilibrium and nonequilibrium states. Topics include: definitions of state, work, energy, entropy, temperature, heat interaction and energy interaction. Applications to simple systems; phase rule; perfect and semi-perfect gas; bulk-flow systems; combustion, energy and entropy balances; availability analysis for thermo-mechanical power generation; and innovative energy-conversion schemes.

Prerequisite: graduate standing or permission of instructor.

Credit 3 units. EN: BME T, TU

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### E37 MEMS 5402 Radiation Heat Transfer

Formulation of the governing equations of radiation heat transfer. Topics include: electromagnetic theory of radiation; properties of ideal and real surfaces; techniques for solutions of heat transfer between gray surfaces; radiation in absorbing, emitting and scattering media.

Credit 3 units. EN: BME T, TU

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### E37 MEMS 5403 Conduction and Convection Heat Transfer

This course examines heat conduction and convection through various fundamental problems that are constructed from the traditional conservation laws for mass, momentum and energy. Problems include the variable-area fin, the unsteady Dirichlet, Robbins and Rayleigh problems, multidimensional steady conduction, the Couette flow problem, duct convection and boundary layer convection. Though some numerics are discussed, emphasis is on mathematical technique and includes the extended power series method, similarity reduction, separation of variables, integral transforms, and approximate integral methods.

Credit 3 units. EN: BME T, TU

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### E37 MEMS 5404 Combustion Phenomena

This course provides an introduction to fundamental aspects of combustion phenomena, including relevant thermochemistry, fluid mechanics, and transport processes as well as the interactions among them. Emphasis is on elucidation of the physico-chemical processes, problem formulation and analytic techniques. Topics covered include non-premixed and premixed flames, deflagrations and

detonations, particle combustion, flame extinction, flame synthesis, pollutant formation and methods of remediation. Contemporary topics associated with combustion are discussed throughout. Prerequisite: Senior or graduate standing or permission of instructor. Same as E44 EECE 512  
Credit 3 units. EN: BME T, TU

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**E37 MEMS 5410 Fluid Dynamics I**

Formulation of the basic concepts and equations governing a Newtonian, viscous, conducting, compressible fluid. Topics include: transport coefficients and the elements of kinetic theory of gases, vorticity, incompressible potential flow; singular solutions; flow over bodies and lifting surfaces; similarity method; viscous flow, boundary layer, low Reynolds number flows, laminar and turbulent flows.  
Credit 3 units. EN: BME T, TU

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**E37 MEMS 5411 Fluid Dynamics II**

Governing equations and thermodynamics relations for compressible flow. Topics include: kinetic theory of gases; steady, one-dimensional flows with friction and heat transfer; shock waves; Rankine-Hugoniot relations; oblique shocks; reflections from walls and flow interfaces, expansion waves, Prandtl-Meyer flow, flow in nozzles, diffusers and inlets, two- and three-dimensional flows; perturbation methods; similarity rules; compressible laminar and turbulent boundary layers; acoustic phenomena. Emphasis is relevant to air vehicles.  
Credit 3 units. EN: BME T, TU

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**E37 MEMS 5412 Computational Fluid Dynamics**

Computational fluid dynamics relevant to engineering analysis and design. Topics include: fundamentals of finite-difference, finite-volume and finite-element methods; numerical algorithms for parabolic, elliptic and hyperbolic equations; convergence, stability and consistency of numerical algorithms; application of numerical algorithms to selected model equations relevant to fluid flow, grid-generation techniques and convergence acceleration schemes. Prerequisite: senior or graduate standing or permission of the instructor.  
Credit 3 units. EN: BME T, TU

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**E37 MEMS 5413 Advanced Computational Fluid Dynamics**

Scope and impact of computational fluid dynamics. Governing equations of fluid mechanics and heat transfer. Three-dimensional grid-generation methods based on differential systems. Numerical methods for Euler and compressible Navier-Stokes equation. Numerical methods for incompressible Navier-Stokes equations. Computation of transonic inviscid and viscous flow past airfoils and wings. Analogy between the equations of computational fluid dynamics, computational electromagnetics, computational aeroacoustics and other equations of computational physics. Non-aerospace applications — bio-fluid mechanics, fluid mechanics of buildings, wind and water turbines, and other energy and environment applications. Prerequisite: MEMS 5412 or permission of the instructor.  
Credit 3 units. EN: TU

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**E37 MEMS 5414 Aeroelasticity and Flow-Induced Vibrations**

This course deals with the interactions between aerodynamics, dynamics and structures in aerospace systems. Topics covered include unsteady aerodynamics, finite-state aerodynamic models, classical fixed-wing flutter, rotary-wing aeroelasticity and experimental methods in aeroelasticity. Emphasis is given to the prediction of flutter and limit cycles in aeroelastic systems.  
Credit 3 units. EN: TU

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**E37 MEMS 5417 Physical Acoustics**

The primary focus of this course is on plane waves as an introduction to acoustical concepts of propagation, reflection and transmission, refraction, normal modes, horn theory, and absorption and dispersion. The course also includes more complicated problems (e.g., those involving spherical and cylindrical waves) and selected topics in applied acoustics including materials/damping, imaging, nondestructive evaluation, and acoustic microfluidics.  
Credit 3 units.

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**E37 MEMS 5420 HVAC Analysis and Design I**

Fundamentals of heating, ventilating, and air conditioning — moist air properties, the psychrometric chart, classic moist air processes, design procedures for heating and cooling systems. Design of HVAC systems for indoor environmental comfort, health, and energy efficiency. Heat transfer processes in buildings. Development and application of techniques for analysis of heating and cooling loads in buildings, including the use of commercial software. Course special topics can include LEED rating and certification, cleanrooms, aviation, aerospace, and naval applications, ventilation loads, animal control facilities, building automation control, and on-site campus tours of state-of-the-art building energy and environmental systems.  
Credit 3 units. EN: BME T, TU

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**E37 MEMS 5421 HVAC Analysis and Design II**

Fundamentals of heating, ventilating, and air conditioning — energy analysis and building simulation, design procedures for building water piping systems, centrifugal pump performance, design of building air duct systems, fan performance, optimum space air diffuser design for comfort, analysis of humidification and dehumidification systems, and advanced analysis of refrigeration systems. HVAC analytical techniques will include the use of commercial software. Course special topics can include LEED rating and certification, management for energy efficiency, energy auditing calculations, aviation, aerospace, and naval applications, ventilation loads, building automation control, and on-site campus tours of state-of-the-art building energy and environmental systems.  
Credit 3 units. EN: BME T, TU

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**E37 MEMS 5422 Solar Thermal Energy Systems**

Fundamentals of radiation heat transfers and solar radiation, including basic terminology, atmospheric scattering and absorption, radiation interactions with surfaces, and selective surfaces. Components, cycles, and materials of concentrating solar power plants, including parabolic trough and solar towers. Overview over thermal storage, other solar thermal technologies and photovoltaics. This course includes a final project. Prerequisite: MEMS 3420 or equivalent.  
Credit 3 units. EN: BME T, TU

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**E37 MEMS 5423 Sustainable Environmental Building Systems**

Sustainable design of building lighting and HVAC systems considering performance, life cycle cost and downstream environmental impact. Criteria, codes and standards for comfort, air quality, noise/vibration and illumination. Life cycle and other investment methods to integrate energy consumption/conservation, utility rates, initial cost, system/component longevity, maintenance cost and building productivity. Direct and secondary contributions to acid rain, global warming and ozone depletion.  
Credit 3 units. EN: BME T, TU

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**E37 MEMS 5424 Thermo-Fluid Modeling of Renewable Energy Systems**

Overview of sustainable energy systems. Fundamentals of energy conversion. Renewable energy sources and energy conversion from wind, biomass, solar-thermal, geothermal and ocean/waves. Applications to energy storage, fuel cells, green air and ground transportation, energy-efficient buildings. Energy-economics modeling, emissions modeling, global warming and climate change. Credit 3 units. EN: BME T, TU

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**E37 MEMS 5425 Thermal Management of Electronics**

As the demand for higher performance electronics continues its exponential growth, transistor density doubles every 18 to 24 months. Electronic devices with high transistor density generate heat and thus require thermal management to improve reliability and prevent premature failure. Demanding performance specifications result in increased package density, higher heat loads and novel thermal management technology. This course gives an overview of thermal management for micro/power electronics systems and helps engineers to develop a fundamental understanding of emerging thermal technologies. This course will include the following topics: background of electronics packaging; thermal design of heat sinks; single phase and multiphase flow in thermal systems; two-phase heat exchange devices for portable and high powered electronic systems; computational fluid dynamics for design of thermal systems. Prerequisites: senior or graduate standing. Credit 3 units. EN: BME T, TU

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**E37 MEMS 5427 Fundamentals of Fuel Cells**

This course is intended for the graduate and senior undergraduate Mechanical Engineering/ Materials Science/Chemical Engineering students interested in obtaining a fundamental background in fuel cell systems. Several types of fuel cells will be discussed, and the fundamental thermodynamics, kinetics of electrochemistry processes, and charge and mass transfer of fuel cells will be introduced. The primary focus will be placed on low temperature fuel cells based on polymer based electrolytes. The design, operation, performance, and reliability/durability of fuel cell systems will be discussed in detail. Specific interests to mechanical engineers, including water management and thermal management, will be a main focus of this course. Furthermore, the state of art research and development of fuel cell technologies may be presented through reading assignments from current literature. Credit 3 units.

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**E37 MEMS 5500 Elasticity**

Elastic constitutive relations for isotropic and anisotropic materials. Formulation of boundary-value problems. Application to torsion, flexure, plane stress, plane strain and generalized plane stress problems. Solution of three-dimensional problems in terms of displacement potentials and stress functions. Solution of two-dimensional problems using complex variables and conformal mapping techniques. Variational and minimum theorems. Credit 3 units. EN: BME T, TU

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**E37 MEMS 5501 Mechanics of Continua**

A broad survey of the general principles governing the mechanics of continuous media. Topics include general vector and tensor analysis, rigid body motions, deformation, stress and strain rate, large deformation theory, conservation laws of physics, constitutive relations, principles of continuum mechanics and thermodynamics, and two-dimensional continua. Prerequisite: ESE 501/502 or instructor's permission. Credit 3 units. EN: BME T, TU

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**E37 MEMS 5502 Plates and Shells**

Introduction to the linear theory of thin elastic plates and shells. The emphasis is on application and the development of physical intuition. The first part of the course focuses on the analysis of plates under various loading and support conditions. The remainder of the course deals mainly with axisymmetric deformation of shells of revolution. Asymptotic methods are used to solve the governing equations. Applications to pressure vessels, tanks, and domes. Prerequisites: BME 240 or MEMS 253; ESE 318 and ESE 319 or equivalent. Credit 3 units. EN: BME T, TU

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**E37 MEMS 5506 Experimental Methods in Solid Mechanics**

Current experimental methods to measure mechanical properties of materials are covered. Lectures include theoretical principles, measurement considerations, data acquisition and analysis techniques. Lectures are complemented by laboratory sections using research equipment such as biaxial testing machines, pressure myographs, indentation devices for different scales, and viscometers. Credit 3 units. EN: BME T, TU

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**E37 MEMS 5507 Fatigue and Fracture Analysis**

The course objective is to demonstrate practical methods for computing fatigue life of metallic structural components. The course covers the three major phases of metal fatigue progression: fatigue crack initiation, crack propagation and fracture. Topics include: stress vs. fatigue life analysis, cumulative fatigue damage, linear elastic fracture mechanics, stress intensity factors, damage tolerance analysis, fracture toughness, critical crack size computation and load history development. The course focus is on application of this technology to design against metal fatigue and to prevent structural failure. Credit 3 units. EN: BME T, TU

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**E37 MEMS 5510 Finite Element Analysis**

This course covers the theory and application of the finite element method. Topics include basic concepts, generalized formulations, construction of finite element spaces, extensions, shape functions, parametric mappings, numerical integration, mass matrices, stiffness matrices and load vectors, boundary conditions, modeling techniques, computation of stresses, stress resultants and natural frequencies, and control of the errors of approximation. Prerequisite: Graduate standing or permission of instructor. Credit 3 units. EN: TU

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**E37 MEMS 5515 Numerical Simulation in Solid Mechanics I**

The solution of 2D and 3D elasticity problems using the finite element method will be covered in this course. Topics include linear elasticity; laminated material; stress concentration; stress intensity factor; solution verification; J integral; energy release rate; residual stress; multi-body contact; nonlinear elasticity; plasticity; and buckling. Prerequisites: MEMS 424 or MEMS 5704; MEMS 5500 or MEMS 5501; and graduate standing or permission of instructor. Credit 3 units.

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**E37 MEMS 5516 Numerical Simulation in Solid Mechanics II**

The solution of 2D and 3D elasticity problems using the finite element method will be covered in this course. Topics include laminates and composite materials; nonlinear elasticity; plasticity; incremental theory of plasticity; residual stress; geometric nonlinearity; membrane and bending load coupling; multi-body contact; stress intensity factor; interference fit; and buckling analysis. Prerequisite: Graduate standing or permission of instructor. Credit 3 units.

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**E37 MEMS 5520 Advanced Analytical Mechanics**

Lagrange's equations and their applications to holonomic and non-holonomic systems will be covered in this course. Topics include reduction of degrees of freedom by first integrals, variational principles, Hamilton-Jacobi theory, general transformation theory of dynamics, applications such as theory of vibrations and stability of motion, and the use of mathematical principles to resolve nonlinear problems. Prerequisite: Senior or graduate standing or permission of instructor. Credit 3 units. EN: TU

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**E37 MEMS 5560 Interfaces and Attachments in Natural and Engineered Structures**

Attachment of dissimilar materials in engineering and surgical practice is a challenge. Bimaterial attachment sites are common locations for injury and mechanical failure. Nature presents several highly effective solutions to the challenge of bimaterial attachment that differ from those found in engineering practice. This course bridges the physiologic, surgical, and engineering approaches to connecting dissimilar materials. Topics covered in this course include natural bimaterial attachments; engineering principles underlying attachments; analysis of the biology of attachments in the body; mechanisms by which robust attachments are formed; concepts of attaching dissimilar materials in surgical practice and engineering; and bioengineering approaches to more effectively combine dissimilar materials. Credit 3 units. EN: BME T, TU

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**E37 MEMS 5561 Mechanics of Cell Motility**

A detailed review of biomechanical inputs that drive cell motility in diverse extracellular matrices (ECMs). This class discusses cytoskeletal machineries that generate and support forces, mechanical roles of cell-ECM adhesions, and regulation of ECM deformations. Also covered are key methods for cell level mechanical measurements, mathematical modeling of cell motility, and physiological and pathological implications of mechanics-driven cell motility in disease and development. Credit 3 units.

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**E37 MEMS 5562 Cardiovascular Mechanics**

This course focuses on solid and fluid mechanics in the cardiac and cardiovascular system. Cardiac and cardiovascular physiology and anatomy. Solid mechanics of the heart, heart valves, arteries, veins and microcirculation. Flow through the heart chambers and blood vessels. Prerequisites: graduate standing or permission of instructor. Credit 3 units. EN: BME T, TU

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**E37 MEMS 5564 Orthopaedic Biomechanics—Cartilage/Tendon**

Basic and advanced viscoelasticity and finite strain analysis applied to the musculoskeletal system, with a primary focus on soft orthopaedic tissues (cartilage, tendon and ligament). Topics include: mechanical properties of cartilage, tendon and ligament; applied viscoelasticity theory for cartilage, tendon and ligament; cartilage, tendon and ligament biology; tendon and ligament wound healing; osteoarthritis. This class is geared to graduate students and upper-level undergraduates familiar with statics and mechanics of deformable bodies. Prerequisites: BME 240 or equivalent. Note: BME 590Z (463/563) Orthopaedic Biomechanics—Bones and Joints is *not* a prerequisite. Credit 3 units. EN: TU

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**E37 MEMS 5565 Mechanobiology of Cells and Matrices**

At the interface of the cell and the extracellular matrix, mechanical forces regulate key cellular and molecular events that profoundly affect aspects of human health and disease. This course offers a detailed review of biomechanical inputs that drive cell behavior in physically diverse matrices. In particular, cytoskeletal force-generation machineries, mechanical roles of cell-cell and cell-matrix adhesions,

and regulation of matrix deformations are discussed. Also covered are key methods for mechanical measurements and mathematical modeling of cellular response. Implications of matrix-dependent cell motility in cancer metastasis and embryonic development are discussed. Prerequisite: graduate standing or permission of the instructor.

Credit 3 units. EN: BME T, TU

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**E37 MEMS 5566 Engineering Mechanobiology**

Engineering Mechanobiology is a new paradigm for understanding and manipulating the biological function of plants, animals, and their cells. Mechanical force has emerged as a critical component of all biological systems, providing mechanisms to sculpt plants and animals during morphogenesis, to enable cell migration, polarization, proliferation, and differentiation in response to physical changes in the environment, and to modulate the function of single molecules. This course provides a foundation for understanding these factors across plant and animal cells. The course begins with an introduction to plant and animal cell biology and principles of signaling, then progresses to an overview of the cell wall and ECM and an introduction to the mechanics and statistical mechanics of solid, viscoelastic, and fibrous continua. The course then focuses on the questions of how do cells feel, how do cells converse with the ECM and wall, and how do cells remember? Knowledge of undergraduate calculus and physics is expected. Credit 3 units. EN: TU

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**E37 MEMS 5601 Mechanical Behavior of Materials**

A materials science-based study of mechanical behavior of materials with emphasis on mechanical behavior as affected by processes taking place at the microscopic and/or atomic level. The response of solids to external or internal forces as influenced by interatomic bonding, crystal/molecular structure, crystalline/noncrystalline defects and material microstructure are studied. The similarities and differences in the response of different kinds of materials viz., metals and alloys, ceramics, polymers and composites are discussed. Topics covered include physical basis of elastic, visco elastic and plastic deformation of solids; strengthening of crystalline materials; visco elastic deformation of polymers as influenced by molecular structure and morphology of amorphous, crystalline and fibrous polymers; deformation and fracture of composite materials; mechanisms of creep, fracture and fatigue; high strain-rate deformation of crystalline materials; and deformation of noncrystalline materials. Credit 3 units. EN: BME T, TU

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**E37 MEMS 5602 Non-metallics**

Structure, mechanical and physical properties of ceramics and cermets, with particular emphasis on the use of these materials for space, missile, rocket, high-speed aircraft, nuclear and solid-state applications. Credit 3 units. EN: BME T, TU

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**E37 MEMS 5603 Materials Characterization Techniques I**

An introduction to the basic theory and instrumentation used in transmission electron, scanning electron and optical microscopy. Practical laboratory experience in equipment operations, experimental procedures and material characterization. Credit 3 units. EN: BME T, TU

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**E37 MEMS 5604 Materials Characterization Techniques II**

Introduction to crystallography and elements of X-ray physics. Diffraction theory and application to materials science including following topics: reciprocal lattice concept, crystal-structure analysis, Laue methods, rotating crystal methods, powder method, and laboratory methods of crystal analysis. Credit 3 units. EN: BME T, TU

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**E37 MEMS 5605 Mechanical Behavior of Composites**

Analysis and mechanics of composite materials. Topics include micromechanics, laminated plate theory, hydrothermal behavior, creep, strength, failure modes, fracture toughness, fatigue, structural response, mechanics of processing, nondestructive evaluation, and test methods. Prerequisite: graduate standing or permission of the instructor.

Credit 3 units. EN: BME T, TU

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**E37 MEMS 5606 Soft Nanomaterials**

Soft nanomaterials, which range from self-assembled monolayers (SAMs) to complex 3D polymer structures, are gaining increased attention owing to their broad-range applications. The course introduces the fundamental aspects of nanotechnology pertained to soft matter. Various aspects related to the design, fabrication, characterization and application of soft nanomaterials are discussed. Topics covered include but are not limited to SAMs, polymer brushes, layer-by-layer assembly, responsive polymers structures (films, capsules), polymer nanocomposites, biomolecules as nanomaterials and soft lithography.

Credit 3 units. EN: BME T, TU

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**E37 MEMS 5607 Introduction to Polymer Blends and Composites**

The course covers topics in multicomponent polymer systems (polymer blends and polymer composites) such as: phase separation and miscibility of polymer blends, surfaces and interfaces in composites, microstructure and mechanical behavior, rubber toughened plastics, thermoplastic elastomers, block copolymers, fiber reinforced and laminated composites, techniques of polymer processing with an emphasis on composites processing, melt processing methods such as injection molding and extrusion, solution processing of thin films, selection of suitable processing methods and materials selection criteria for specific applications. Advanced topics include: nanocomposites such as polymer/CNT composites, bioinspired nanocomposites, and current research challenges. Prerequisite: MEMS 3610 or equivalent or permission of instructor.

Credit 3 units. EN: BME T, TU

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**E37 MEMS 5608 Introduction to Polymer Science and Engineering**

Topics covered in this course are: the concept of long-chain or macromolecules, polymer chain structure and configuration, microstructure and mechanical (rheological) behavior, polymer phase transitions (glass transition, melting, crystallization), physical chemistry of polymer solutions (Flory-Huggins theory, solubility parameter, thermodynamics of mixing and phase separation), polymer surfaces and interfaces, overview of polymer processing (extrusion, injection molding, film formation, fiber spinning) and modern applications of synthetic and bio-polymers.

Credit 3 units. EN: BME T, TU

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**E37 MEMS 5610 Quantitative Materials Science & Engineering**

This course will cover the mathematical foundation of primary concepts in materials science and engineering. Topics covered include mathematical techniques in materials science and engineering; Fourier series; ordinary and partial differential equations; special functions; matrix algebra; and vector calculus. Each topic will be followed by its application to concepts in thermodynamics; kinetics and phase transformations; structure and properties of hard and soft matter; and characterization techniques. This course is intended especially for students pursuing graduate study in materials science.

Credit 3 units. EN: BME T, TU

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**E37 MEMS 5611 Principles and Methods of Micro and Nanofabrication**

A hands-on introduction to the fundamentals of micro- and nano-fabrication processes with emphasis on cleanroom practices. The physical principles of oxidation, optical lithography, thin film deposition, etching and metrology methods will be discussed, demonstrated and practiced. Students will be trained in cleanroom concepts and safety protocols. Sequential micro-fabrication processes involved in the manufacture of microelectronic and photonic devices will be shown. Training in imaging and characterization of micro- and nano-structures will be provided. Prerequisite: graduate or senior standing or permission of the instructor

Credit 3 units. EN: BME T, TU

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**E37 MEMS 5612 Atomistic Modeling of Materials**

This course will provide a hands-on experience using atomic scale computational methods to model, understand and predict the properties of real materials. It will cover modeling using classical force-fields, quantum-mechanical electronic structure methods such as density functional theory, molecular dynamics simulations, and Monte Carlo methods. The basic background of these methods along with examples of their use for calculating properties of real materials will be covered in the lectures. Atomistic materials modeling codes will be used to calculate various material properties. Prerequisites: MEMS 3610 or equivalent or permission of instructor.

Credit 3 units. EN: BME T, TU

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**E37 MEMS 5613 Biomaterials Processing**

Biomaterials with 3D structures are important for tissue regeneration. The goal of this class is to introduce various types of biomaterials and fabrication approaches to create 3D structures. The relationship between material properties, processing methods, and design will be the primary focus. The topics include degradable biomaterials for scaffold fabrication, processing of tissue engineering scaffolds, processing of tissue engineering hydrogels, processing of drug delivery systems, and scaffold surface modification.

Credit 3 units. EN: BME T, TU

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**E37 MEMS 5614 Polymeric Materials Synthesis and Modification**

Polymer is a class of widely used material. Polymer performance is highly dependent on its chemical properties. The goal of this class is to introduce methods for the synthesis and modification of polymers with different chemical properties. The topics include free radical polymerization, reversible addition-fragmentation chain transfer polymerization, atom transfer radical polymerization, step growth polymerization, cationic polymerization, anionic polymerization, ring-opening polymerization, and bulk and surface modification of polymers.

Credit 3 units. EN: BME T, TU

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**E37 MEMS 5615 Metallurgy and Design of Alloys**

The design of materials used in critical structures (e.g., airplanes) entails optimizing and balancing multiple properties (e.g., strength, durability, corrosion resistance) to satisfy often conflicting requirements (e.g., better fuel efficiency, lower cost, operation in extreme conditions). Properties of metallic materials are determined by their "microstructure," which in turn is determined by their compositions and processing paths. An understanding of the multivariate relationships among compositions, processing parameters, microstructures, and properties is therefore essential to designing alloys and predicting their behavior in service. This course will discuss these relationships, with emphasis on the hierarchy of microstructural features, how they are achieved by processing, and how they interact

to provide desirable property combinations -- essentially the physical metallurgy of alloys. This course will focus on high-performance alloys presently used in airframes as well as alloy design for state-of-the-art processes such as additive manufacturing. Prerequisite: MEMS 3610. Credit 3 units. EN: BME T, TU

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### **E37 MEMS 5616 Defects in Materials**

Defects in materials play a critical role in controlling the properties of solids, which makes them interesting and necessary to study. The objective of this course is to provide a broad overview of defects in crystalline solids, their effect on properties, and methods of characterizing them. Course topics include crystal structures, defect classification, defect interactions, the role of defects in controlling properties of materials, and characterization techniques. Credit 3 units. EN: BME T, TU

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### **E37 MEMS 5617 Advanced Study of Solid-State Electronics**

This course is designed for students who want to pursue advanced study in solid-state materials and electronic applications. It will provide fundamentals of 1) basic solid-state physics 2) phase equilibria and fabrication of emerging solid-state materials: 3D thin films (III-V, III-N, complex oxide) and low dimensional materials (0D, 1D, 2D) 3) electrical and photonic properties and 4) property manipulation: doping and strain engineering. Students will learn various emerging solid-state electronic devices such as HEMT, nano-materials based TFT, QD LEDs, nanogenerators, advanced solar cells and more. The goal of this course is to help students understand fundamentals to design new solid-state device architectures. The course is particularly beneficial for students who have an interest in the emerging semiconductor field. Credit 3 units. EN: BME T, TU

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### **E37 MEMS 5618 Electronic Behavior of Materials**

This course is designed for students who want to understand electronic behavior of materials which is related to electronic/semiconductor research and industry. It will provide fundamentals of 1) crystal structures and bonding of electronic materials, 2) electronic movement in various materials, 3) electronic behavior in junctions, 4) electronic, optic, and magnetic properties correlation, 5) various electronic applications such as solar cells, light-emitting diodes, and transistors. The goal of the course is to help students understand basic knowledge and fundamental about electronic behavior in materials. The course is particularly beneficial for students who have an interest in the semiconductor research and industry. Credit 3 units.

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### **E37 MEMS 5619 Thermodynamics of Materials**

Thermodynamics of mixtures and phase equilibria in materials systems. The course will review the laws of thermodynamics and introduce the principles of statistical mechanics along with thermodynamic variables and the relationships between them. It will cover thermodynamic equilibria in unary and multicomponent systems along with the construction of phase diagrams. The use of thermodynamics for understanding surfaces and interfaces, defects, chemical reactions, and other technical applications will be emphasized. Credit 3 units.

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### **E37 MEMS 5700 Aerodynamics**

This course introduces fundamental concepts of aerodynamics, equations of compressible flows, irrotational flows and potential flow theory, singularity solutions, circulation and vorticity, the Kutta-Joukowski theorem, thin airfoil theory, finite wing theory, slender body theory, subsonic compressible flow and the Prandtl-Glauert rule, supersonic thin airfoil theory, an introduction to performance, and basic concepts of airfoil design. Prerequisite: MEMS 3410 or permission of instructor.

Credit 3 units. EN: BME T, TU

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### **E37 MEMS 5701 Aerospace Propulsion**

Propeller, jet, ramjet and rocket propulsion. Topics include: fundamentals of propulsion systems, gas turbine engines, thermodynamics and compressible flow, one-dimensional gas dynamics, analysis of engine performance, air breathing propulsion system, the analysis and design of engine components, and the fundamentals of ramjet and rocket propulsion. Credit 3 units. EN: BME T, TU

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### **E37 MEMS 5703 Analysis of Rotary-Wing Systems**

This course introduces the basic physical principles that govern the dynamics and aerodynamics of helicopters, fans and wind turbines. Simplified equations are developed to illustrate these principles, and the student is introduced to the fundamental analysis tools required for their solution. Topics include: harmonic balance, Floquet theory and perturbation methods. Credit 3 units. EN: BME T, TU

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### **E37 MEMS 5704 Aircraft Structures**

Basic elements of the theory of elasticity; application to torsion of prismatic bars with open and closed thin-wall sections; the membrane analogy; the principle of virtual work applied to 2D elasticity problems. Bending, shear and torsion of open and closed thin-wall section beams; principles of stressed skin construction, structural idealization for the stress analysis of wings, ribs and fuselage structures. Margin of safety of fastened connections and fittings. Stability of plates, thin-wall section columns and stiffened panels. Application of the finite element method for the analysis of fastened connections, structural fittings and problems of local stability of aircraft structural components. Credit 3 units.

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### **E37 MEMS 5705 Wind Energy Systems**

A comprehensive introduction to wind energy systems, a practical means of extracting green and sustainable energy. Topics include: a historical perspective of wind turbines; horizontal axis and vertical axis wind turbines; the basic parameters such as power rating and efficiency; the structural components ranging from blade and hub to nacelle and tower; wind turbine aerodynamics, aeroelasticity and control systems; blade fatigue; statistical wind modeling; unsteady airfoil aerodynamics and downstream wake; and environmental considerations such as noise and aesthetics. Prerequisite: senior or graduate standing in engineering or permission of the instructor. Credit 3 units. EN: BME T, TU

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### **E37 MEMS 5706 Aircraft Performance**

This course introduces the principles and applications of aerodynamics to determine the performance of typical jet engine and propeller airplanes. The performance calculations include flight conditions of takeoff, climb, level flight, and landing. The topics covered also include range and endurance computation, turning flight, flight envelope, constraint analysis and design process. The knowledge and skill gained in this course can be readily applied in the preliminary design of an airplane. Prerequisite: senior or graduate standing in engineering, or permission of the instructor. Credit 3 units. EN: BME T, TU

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### **E37 MEMS 5707 Flight Dynamics**

The course objective is to introduce methods for analyzing and simulating flight vehicle dynamics and to assess performance characteristics. Topics will include: aerodynamics, structural dynamics, vehicle forces and moments, vehicle equations of motion, rigid body and flexible body considerations, model linearization, longitudinal

and lateral stability, stability and control augmentation, and aircraft handling qualities. The course focus is on the application of flight dynamics principles and MATLAB will be used extensively for modeling and simulation assignments and demonstrations.

Credit 3 units. EN: TU

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### **E37 MEMS 5801 Micro-Electro-Mechanical Systems I**

Introduction to MEMS: Microelectromechanical systems (MEMS) are ubiquitous in chemical, biomedical and industrial (e.g., automotive, aerospace, printing) applications. This course covers important topics in MEMS design, micro-/nanofabrication, and their implementation in real-world devices. The course includes discussion of fabrication and measurement technologies (e.g., physical/chemical deposition, lithography, wet/dry etching, and packaging), as well as application of MEMS theory to design/fabrication of devices in a cleanroom. Lectures cover specific processes and how those processes enable the structures needed for accelerometers, gyros, FR filters, digital mirrors, microfluidics, micro total-analysis systems, biomedical implants, etc. The laboratory component allows students to investigate those processes first-hand by fabricating simple MEMS devices.

Credit 3 units. EN: BME T, TU

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### **E37 MEMS 5912 Biomechanics Journal Club**

This journal club is intended for graduate students and advanced undergraduates with an interest in biomechanics. We review landmark and recent publications in areas such as brain, cardiovascular and orthopedic biomechanics, discussing both experimental and modeling approaches. This course meets once weekly at a time to be arranged.

Credit 1 unit. EN: TU

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### **E37 MEMS 597 MEMS Research Rotation**

Independent research project that will be determined jointly by the doctoral student and the instructor. Assignments may include background reading, presentations, experiments, theoretical, and/or modeling work. The goal of the course is for the doctoral student to learn the background, principles and techniques associated with research topics of interest and to determine a mutual fit for the student's eventual doctoral thesis laboratory.

Credit 3 units.

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### **E37 MEMS 598 Energy Analysis and Design Project**

The Energy Analysis and Design Project is designed to provide mechanical engineering skills in energy applications, renewable energy, and technologies related to energy which can involve heat transfer, thermodynamics, and fluid mechanics. The project topic can be chosen by the student or can be developed by both the student and faculty sponsor. The subsequent research and analysis, conducted under the guidance and direction of the faculty sponsor, results in a final project report that is approved by the faculty sponsor. The course is normally completed over one or two semesters. Recent projects have included: Energy Modeling and Efficiency Improvements: A Comparison of TRACE 700 and eQuest, Analysis of Hydroelectric Power, Optimization of Residential Solar Thermal Heating in the United States, Analysis of Ocean Thermal Energy Conversion Systems, Laboratory Plug Load Analysis and Case Study, Modeling and Optimizing Hydronic Radiant Heating and Cooling Systems using Comsol Multiphysics, CFD Analysis in HVAC Applications, Energy Analysis of Waste Disposal Methods, CFD Analysis of Containment Solutions for Data Center Cooling, Energy Recovery Ventilation, Comparative Study of Green Building Rating Systems, Grid Energy Storage, Protection of Permafrost Under the Qinghai-Tibet Railway by Heat Pipe Technology, Investing in Residential Solar Photovoltaic Systems, How Piping Layout Effects Energy Usage, and Comparison of Building Energy Savings Between China and the United States.

Credit variable, maximum 3 units.

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### **E37 MEMS 599 Master's Research**

Credit variable, maximum 6 units.

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### **E37 MEMS 600 Doctoral Research**

Credit variable, maximum 9 units.

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