Mechanical Engineering & Materials Science

The Department of Mechanical Engineering & Materials Science offers both **PhD** and **DSc** programs in **Mechanical Engineering** and **Aerospace Engineering** as well as a **DSc in Materials Science**. The department's research strengths include biomechanics and biotechnology, energy and sustainability, advanced materials and aerospace systems. The doctoral student works in conjunction with their advisor to design the program of study and the research project. The dissertation is defended at the end of the research effort. A typical time to PhD after the completion of the undergraduate engineering degree is four to five years, but the length of the program may vary, depending on the individual and the area of study.

The Department of Mechanical Engineering & Materials Science offers a **Master of Science (MS)** degree in **Mechanical Engineering, Aerospace Engineering,** or **Materials Science and Engineering**. The department also offers a **Master of Engineering in Mechanical Engineering** for those coming from fields closely related to mechanical engineering. The MS degrees can be completed using either a course option or a thesis option. For the thesis option, the student will work closely with a faculty advisor on the thesis project. A typical time for the completion of an MS or MEng degree is one and one-half to two years, with the thesis option usually taking longer than the course option.

Faculty contact for the PhD program: Amit Pathak

Faculty contact for the MS and DSc programs: David Peters

Faculty contact for the MS in Materials Science & Engineering: Katharine Flores

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

Faculty

Chair

Philip V. Bayly
The Lee Hunter Distinguished Professor of Mechanical Engineering
PhD, Duke University
Nonlinear dynamics, vibrations, biomechanics

Associate Chairs

David A. Peters (Mechanical Engineering)
McDonnell Douglas Professor of Engineering
PhD, Stanford University
Aeroelasticity, vibrations, helicopter dynamics, aerodynamics

Katharine M. Flores (Materials Science)
Christopher I. Byrnes Professor of Engineering
PhD, Stanford University
Mechanical behavior of structural materials

Endowed Professors

Ramesh K. Agarwal
William Palm Professor of Engineering
PhD, Stanford University
Computational fluid dynamics, computational physics

Guy M. Genin
Harold & Kathleen Faught Professor of Mechanical Engineering
PhD, Harvard University
Solid mechanics, fracture mechanics

Jianjun Guan
Earl E. & Myrtle E. Walker Professor of Engineering
PhD, Zhejiang University
Biomimetic biomaterials synthesis, scaffold fabrication

Mark J. Jakiela
Lee Hunter Professor of Mechanical Design
PhD, University of Michigan
Mechanical design, design for manufacturing, optimization, evolutionary computation

Srikanth Singamaneni
Lilyan and E. Lisle Hughes Professor of Mechanical Engineering
PhD, Georgia Institute of Technology
Microstructures of cross-linked polymers

Professors

Amit Pathak
PhD, University of California, Santa Barbara
Cellular biomechanics

Jessica E. Wagenseil
DSc, Washington University
Arterial biomechanics

Associate Professors

Spencer P. Lake
PhD, University of Pennsylvania
Soft-tissue biomechanics

Xianglin Li
PhD, University of Connecticut
Multiphase heat and mass transfer in energy systems; computational fluid dynamics

J. Mark Meacham
PhD, Georgia Institute of Technology
Micro-/nanotechnologies for thermal systems and the life sciences

Rohan Mishra
PhD, The Ohio State University
Computational materials science

Patricia B. Weisensee
PhD, University of Illinois at Urbana-Champaign
Thermal fluids

Assistant Professors

Sang-Hoon Bae
PhD, University of California, Los Angeles
Materials growth, optoelectronics, renewable energy

Matthew R. Bersi
PhD, Yale University
Biomedical engineering

Professor of the Practice

Swami Karunamoorthy
DSc, Washington University
Helicopter dynamics, engineering education

Teaching Professors

Emily J. Boyd
PhD, University of Texas at Austin
Thermofluids

Ruth J. Okamoto
DSc, Washington University
Biomechanics, solid mechanics

Research Professor

Anders E. Carlsson
PhD, Harvard University
Biophysical Modeling, Mechanobiology

Joint Faculty

Richard L. Axelbaum (Energy, Environmental & Chemical Engineering)
Stifel & Quinette Jens Professor of Environmental Engineering Science
PhD, University of California, Davis
Combustion, nanomaterials

Christopher Cooper (Energy, Environmental & Chemical Engineering)
PhD, Stanford University
Responsive, soft materials for applications in energy storage, environmental sustainability and human health

Elliot L. Elson (Biochemistry & Molecular Biophysics)
Professor Emeritus of Biochemistry & Molecular Biophysics
PhD, Stanford University
Biochemistry, molecular biophysics

Michael D. Harris (Physical Therapy, Orthopaedic Surgery, and Mechanical Engineering & Materials Science)
PhD, University of Utah
Whole body and joint-level orthopaedic biomechanics

Kenneth F. Kelton (Physics)
Arthur Holly Compton Professor of Arts & Sciences
PhD, Harvard University
Study and production of titanium-based quasicrystals and related phases

Eric C. Leuthardt (Neurological Surgery and Biomedical Engineering)
MD, University of Pennsylvania School of Medicine
Neurological surgery

Lori Setton (Biomedical Engineering)
Lucy and Stanley Lopata Distinguished Professor of Biomedical Engineering
PhD, Columbia University
Biomechanics for local drug delivery, tissue regeneration specific to the knee joints and spine

Matthew J. Silva (Orthopaedic Surgery)
Julia and Walter R. Peterson Orthopaedic Research Professor
PhD, Massachusetts Institute of Technology
Biomechanics of age-related fractures and osteoporosis

Simon Tang (Orthopaedic Surgery and Biomedical Engineering)
PhD, Rensselaer Polytechnic Institute
Biological mechanisms

Senior Professors

Phillip L. Gould
PhD, Northwestern University
Structural analysis and design, shell analysis and design, biomechanical engineering

Kenneth L. Jerina
DSc, Washington University
Materials, design, solid mechanics, fatigue, fracture

Shankar M.L. Sastry
PhD, University of Toronto
Materials science, physical metallurgy

Barna A. Szabo
PhD, State University of New York at Buffalo
Numerical simulation of mechanical systems, finite-element methods

Senior Lecturer

J. Jackson Potter
PhD, Georgia Institute of Technology
Senior design

Louis G. Woodhams
BS, University of Missouri–St. Louis
Computer-aided design

Lecturers

Chiamaka Asinugo
MS, Washington University
Mechanical engineering design

Sharniece Holland
PhD, University of Alabama
Additive manufacturing, mathematics

Jeffery Krampf
MS, Washington University
Fluid mechanics, modeling, design

H. Shaun Sellers
PhD, Johns Hopkins University
Mechanics, materials

Adjunct Instructors

Ricardo L. Actis
DSc, Washington University
Finite element analysis, numerical simulation, aircraft structures

Robert G. Becnel
MS, Washington University
FE review

Andrew W. Cary
PhD, University of Michigan
Computational fluid dynamics

Richard S. Dyer
PhD, Washington University
Propulsion, thermodynamics, fluids

Timothy W. Jackson
PhD, University of Washington
Structural analysis, dynamics

Richard R. Janis
MS, Washington University
Building environmental systems

Gary D. Renieri
PhD, Virginia Polytechnic Institute and State University
Structural applications, composite materials

Krishnan K. Sankaran
PhD, Massachusetts Institute of Technology
Metallic materials

Michael C. Wendl
DSc, Washington University
Mathematical theory, computational methods in biology and engineering

Degree Requirements

Please visit the following pages for more information about Mechanical Engineering & Materials Science graduate programs:

- Doctoral Degrees
- Master of Science in Mechanical Engineering (MSME)
- Master of Science in Aerospace Engineering (MSAE)
- Master of Science (MS) in Materials Science and Engineering
- Master of Engineering (MEng) in Mechanical Engineering

Courses

Visit online course listings to view semester offerings for E37 MEMS.

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.

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

E37 MEMS 501 Graduate Seminar
This is a required pass/fail course for masters 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.

E37 MEMS 5102 Materials Selection in Design
Analysis of the scientific bases of material behavior in the light of research contributions of the last 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 will be placed on mechanical properties, acoustical, optical, thermal and other properties of interest in design will be discussed.
Credit 3 units. EN: BME T, TU

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; multi-disciplinary 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

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 will be reinforced with a number of examples from recently published research. Applications will include aeroelastic flutter, impact dynamics, machine-tool vibrations, cardiac arrhythmias, and control of chaotic behavior.
Credit 3 units. EN: BME T, TU

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

E37 MEMS 5401 General Thermodynamics
General foundations of thermodynamics valid for small and large systems, and for equilibrium and non-equilibrium 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

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, multi-dimensional 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

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

E37 MEMS 5410 Fluid Dynamics I
This course covers the fundamentals of incompressible fluid flow. Topics include: fundamental equations (continuity and Navier-Stokes Equations), basic solutions for steady and unsteady flows; laminar and turbulent boundary layer analysis; free shear flows; integral analysis, similarity solutions; turbulent flow on plates, pipes, and channels; computational fluid dynamics software
Credit 3 units. EN: BME T, TU

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

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. Prerequisites: Senior or graduate standing or permission of the instructor.
Credit 3 units. EN: BME T, TU

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. Prerequisites: MEMS 5412 or permission of the instructor.
Credit 3 units. EN: TU

E37 MEMS 5414 Aeroelasticity & Flow-Induced Vibrations
This course deals with the interactions between aerodynamics, dynamics and structures in aerospace systems. Topics covered will include unsteady aerodynamics, finite-state aerodynamic models, classical fixed-wing flutter, rotary-wing aeroelasticity and experimental methods in aeroelasticity. Emphasis will be given to the prediction of flutter and limit cycles in aeroelastic systems
Credit 3 units. EN: TU

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. EN: BME T, TU

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

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

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

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.

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

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, two-dimensional continua. Prerequisite: ESE 501/502 or instructor's permission.
Credit 3 units. EN: BME T, TU

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

E37 MEMS 5506 Experimental Methods in Solid Mechanics
Current experimental methods to measure mechanical properties of materials will be 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

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. Pre-requisite: MEMS 350
Credit 3 units. EN: BME T, TU

E37 MEMS 5508 Image-based Measurement of Shape, Motion, and Deformation
Many engineering analysis and design applications require the knowledge of how materials respond to applied loads. This course will provide an overview of various imaging and computer vision techniques to measure full-field object characteristics including shape, motion, and deformation. Selected topics will include basic geometrical optics, lenses and mirrors, single camera models and calibration, image processing, digital image correlation (in multiple dimensions), stereo vision, photogrammetry, strain calculations, and inverse methods. This course is intended for graduate and upper-level students interested in experimental solid mechanics and practical applications of image processing and analysis.
Credit 3 units.

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

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

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

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

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 inter atomic bonding, crystal/molecular structure, crystalline/non crystalline defects, and material microstructure will be studied. The similarities and differences in the response of different kinds of materials viz., metals and alloys, ceramics, polymers, and composites will be 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 non crystalline materials.
Credit 3 units. EN: BME T, TU

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

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

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

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

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 intends to introduce the fundamental aspects of nanotechnology pertained to soft matter. Various aspects related to the design, fabrication, characterization and application of soft nanomaterials will be discussed. Topics that will be covered include but 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

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

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

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

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

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

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

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 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

E37 MEMS 5615 Metallurgy and Design of Alloys
The design of materials used in critical structures such as in airplanes entails optimizing and balancing multiple properties (e.g., strength, fracture toughness, 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. The discussion will be based on examples from alloys used in airframes, engines, and automobiles and on their design for state-of-the-art processes such as additive manufacturing. Prerequisite: MEMS 3610.
Credit 3 units. EN: BME T, TU

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

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

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.

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.

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

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

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

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.

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

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

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

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 will cover important topics in MEMS design, micro-/nanofabrication, and their implementation in real-world devices. The course will include 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 will 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 will allow students to investigate those processes first-hand by fabricating simple MEMS devices.
Credit 3 units. EN: BME T, TU

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.

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 Quinghai-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.

E37 MEMS 599 Masters Research
Credit variable, maximum 6 units.

E37 MEMS 600 Doctoral Research
Credit variable, maximum 9 units.