

# ENGINEERING SCIENCE (ESC)

## ESC 501: Solar Cell Devices

3 Credits

Principles of photovoltaic energy conversion and their utilization in engineering devices. Emphasis on current solar cell research and development efforts. ESC 501 Solar Cell Devices (3) Photovoltaic energy conversion using organic and inorganic absorbers and liquid and solid materials is examined in depth. The emphasis is on photovoltaic energy conversion using sun light and covers solar cell device physics, materials, and design as well as all four types of photovoltaic structures; i.e., homojunctions, heterojunctions, surface barrier cells, and dye sensitized cells. Basic topics covered in the course include: solar spectra and industry standards; material properties and physics key to photovoltaic structures; and the role of scale in photovoltaics including the use of nano-structures. Computer modeling topics include an introduction to the AMPS code for transport analysis and an introduction to Maxwell's equations solvers for light trapping analysis. The use of such codes in the design of solar cells for light, carrier collection, and efficiency optimization is explored. Solar cell industry developments and research advancements are discussed throughout the course.

**Prerequisite:** E E 442 or PHYS 412

Cross-Listed

## ESC 502: Semiconductor Heterojunctions and Applications

3 Credits

Theory, fabrication techniques, and electronic applications of semiconductor heterojunctions, including metal-semiconductor and electrolyte-semiconductor junctions.

**Prerequisite:** E SC 314 or E SC 414M

## ESC 503: Low Dimensional Nanoelectronics

3 Credits

This course will cover advanced concepts which are essential to understand modern state-of-the art electronic devices based on novel nanomaterials. The course is designed for experimentalists, material scientists, and device physicists who are interested to learn how carrier transport takes place in low dimensional semiconductors such as zero dimensional quantum dots, one dimensional nanotubes (CNT), quasi-one dimensional nanowires, and two dimensional nanosheets (graphene, MoS<sub>2</sub>). The course will begin with a review of semiconductor physics which includes Fermi-Dirac statistics, dispersion relationship (E-k), density of states, electron density, various definition of carrier velocities, and discussion on traditional drift-diffusion (DD) model for carrier transport. We will then adopt a bottom-up approach to understand current flow through a device with only one energy level, which will eventually lead to the formalism of Landauer-Datta (LD) transport model for ballistic conductors. The concept of quantum conductance and transport modes will be taught. We will also learn how to incorporate different scattering mechanisms into the LD model. The LD model will be used to understand current flow through a carbon nanotube (CNT), graphene, and MoS<sub>2</sub>. Next, the LD model will be extended to describe heat flow in nanomaterials which forms the basis of various thermoelectric phenomena such as the Seebeck effect, Peltier cooling, etc. The second part of the course will focus on the electrostatics and transport in ballistic and quasi-ballistic metal-oxide-semiconductor

field effect transistors (MOSFETs). We will learn how to solve Poisson's equation self-consistently with LD model for Si MOSFET and extend it to ultra-thin-body-silicon-on-insulator (UTMSOI) FETs, FinFETs, CNTFETs, graphene and MoS<sub>2</sub> FETs. The advantage of ultra-thin body channel material for MOSFET scaling and how nanomaterials help in overcoming short channel effects will also be taught. Concepts such as quantum capacitance limit will be introduced. Contact resistance and related issues will also be extensively taught. Various beyond Boltzmann novel device concepts tunnel FETs, phase change FETs, negative capacitance FETs, excitonic FETs, strain FETs for low power computing will be introduced. In the third part of the course we will learn multiple quantum mechanical effects related to transport in nanomaterials such as Quantum Hall effect, energy level broadening, and Coulomb Blockade phenomena in quantum dots. We will also learn multi-electron picture through Folk's Space in order to understand many body interactions. Finally, we will study the matrix version of Schrodinger equation to derive band-structure of different nanomaterials using nearest neighbor semi-empirical approach in orthogonal basis. Generalized transport equations will be obtained using Non Equilibrium Green's Function (NEGF) formalism. Students will be asked to do literature reviews on multiple topics taught in the course. They will also use their learning and solid foundation developed through out the course to execute group projects that are either exploratory in nature or relevant to the state-of-the-art technological problems of the semiconductor industry. This will prepare them for independent and innovative research.

## ESC 505: Wearable Electronics

3 Credits

Recent advances in wearable electronics have led to the development of powerful biomedical devices that monitor vital physiological signals and provide means of treatment. Conventional electronics today are formed on the planar surfaces of brittle wafer substrates and are not compatible with the textured skin or tissue surfaces. Therefore, stretchable and resorbable electronics are the two missing links in the design process of implantable monitors and in-vivo therapeutics. Novel design strategies present unique opportunities to address the challenges in such a potential medical device that (a) integrates with human physiology, and (b) dissolves completely after its effective operation. In this course, we will apply novel strategies to address challenging issues in these emerging electronics, with examples ranging from sensors for thermal, mechanical, electrical, and electrochemical monitoring to integrated systems that can serve as human-machine interfaces and biomedical devices. This course covers a broad range of topics related to the novel strategies for the emerging electronics, including design and analysis of stretchable and dissolvable electronics, manufacturing techniques for biomedical devices, characterization techniques of soft sensors and actuators, applications, and opportunities for these emerging electronics, among others.

## ESC 507: Bioarchitecture

3 Credits

Fundamentals of biological architecture observed in nature with emphasis on symmetry and topology with examples from recent literature. Bioarchitecture is the use and implementation of concepts and principles from nature to design functional materials, devices, and systems. Inspired by the structure and utility of biological surfaces, various surfaces have been engineered with micro- and nanoscale features. Bio-derived materials hold great promise to provide a broad range of industrial solutions. These materials can be shaped into

various geometries such as fibers, colloids, and thin films. Recombinant expression or direct extraction of bio-derived materials from biological organisms can provide a new generation of recyclable-engineered materials. Understanding the structures and functional characteristics of biological architecture will expedite the design, fabrication, and synthesis of eco-friendly, recyclable, advanced materials, with novel physical properties.

ESC 514: Engineering Science and Mechanics Seminar

1 Credits/Maximum of 99

Current literature and special problems in engineering mechanics.

Cross-listed with: EMCH 514

ESC 515: Research Practices in Engineering

3 Credits

This course is designed to help incoming graduate students prepare to conduct independent thesis research as part of a research group and become part of the broader research enterprise at Penn State. It introduces students to various elements in the research practices domain categorized as discovery and innovation, cooperation, governance, daily life, resources, and career. The elements of discovery and innovation are to: know the state of the art and knowledge gaps, know how to formulate a research objective, know the past literature, think critically and make connections, know what colleagues in your community do, create intellectual merit, and know what facilities are available. Cooperation entails: sharing information, cooperatively developing documents, developing modular procedures/codes, and being part of a team. Participation in governance involves: reviewing the work of others (publications and proposals) and knowing how to become part of professional societies and the review process for funding agencies. Daily life includes knowing the scientific method in general, how research groups function, documentation of progress, ethical norms, the forms of bias, safety standards, handling data and the associated ethics, protecting privacy, how to work with human subjects, humane treatment of animals, and reporting misconduct. Conducting research requires resources and knowing about funding sources, labor and material costs, and lab usage fees. Research practices are integral to establishing a career through planning, networking, dissemination of results, and incorporation of feedback into plans and documents. This course will introduce students to a range of good research practices in Engineering. Topics covered will include: the organization of a research group; a set of standard tools for performing research including writing, bibliographic organization, version control, data management and backups; tools and good practices for collaboration; good laboratory practices; responsible conduct of research. A large fraction of the course will focus on how to design and conduct research, including reading papers critically, developing bibliographies, writing papers, designing a research project, and writing a research proposal. Full participation in the course satisfies the university requirements for scholarship and research integrity training.

**Recommended Preparation:** This course is intended for incoming graduate students to prepare them to become independent researchers.

ESC 518: Bioprinting

3 Credits

This course covers the principles of bioprinting in tissue engineering and regenerative medicine for use in fabrication of biomedical related

products such as implants, tissue scaffolds, engineered tissues, organs and biological systems. Topics include Tissue Engineering, 3D Printing, Layered Manufacturing and Rapid Tooling in Medicine, Design for Bioprinting, The Bioink, Extrusion-based Bioprinting, Droplet-based Bioprinting, Laser-based Bioprinting, Bioprinters and their components, Application Areas of Bioprinting and New Frontiers in Tissue Engineering such as Organ Printing.

ESC 520: Engineering at the Nano-scale

3 Credits

Engineering at the nano-scale, its current applications, its future directions, and its impact on society are the subjects of E SC 520. The uniqueness of the nano-scale is addressed by first reviewing the basic aspects of our picture of the physical world (e.g. Newtonian and quantum mechanics, geometrical and physical optics) and then exploring the relative impact of these aspects on physical, chemical, and biological phenomena at the nano-scale. Which phenomena dominate as a function of scale and how this competition affects properties and structures is explored in detail allowing the opportunities of the nano-scale to emerge. Impact of the uniqueness of the nano-scale on engineering and the possibilities offered for engineering applications, ranging from manufacturing processing to better building materials to better drug delivery systems, are discussed throughout the course. These creative possibilities afforded by engineering at the nano-scale are highlighted by a varying array of applications taken from fields including medicine and biotechnology, agriculture and food, environmental mitigation, electronics and spintronics, opto-electronics, photonics, sensing, materials, transportation technology, energy production, energy storage, and informatics.

**Prerequisite:** E SC 412

ESC 521: Pattern Transfer at the Nano-scale

3 Credits

Engineering at the nano-scale often requires creating and then transferring a pattern when fabricating a desired nano-scale structure. This course explores the basic processes of pattern design and then addresses the techniques used to transfer a nano-scale pattern to a surface or structure. The course looks into pattern transfer techniques that employ particles, photons, and additional chemical and physical means as the transfer mechanisms. Included in the photon approaches are studies of deep UV and X-ray pattern transfer. Particle transfer mechanisms discussed include ion and neutral particle approaches. Physical-contact pattern transfer is also explored including discussions of nano-imprinting lithography, nano-molding lithography, and scanning probe lithography. Chemical pattern transfer is another approach to pattern transfer and one that uniquely uses chemical processes to create patterns. Examples to be discussed in this course include molecular self-assembly lithography and block co-polymer lithography. Emerging pattern transfer techniques, such as magneto-lithography, will be included in E SC 521 for completeness. In many of these pattern transfer methodologies, a "writing" of the transferring pattern into some intermediary medium termed a resist is required. In pattern technologies requiring resists, the resist materials and their positioning as well as required physical and chemical properties will be discussed.

**Prerequisite:** ESC 520

Cross-listed with: NANO 521

ESC 522: Fabrication and Characterization for Top-down Nano-manufacturing

3 Credits

There are two broad approaches to fabrication and manufacturing at the nano-scale. They are bottom-up and top-down nanofabrication. The two approaches are complementary, with the former having strong ties to biology and the latter having very strong ties to traditional semiconductor processing. E SC 522 focuses on top-down nanofabrication which makes use of two distinct approaches: additive processes and subtractive processes. These are studied in detail in this course by first focusing on the additive processes which deposit or grow materials. The effort then shifts to the subtractive processes which remove materials with a mixture of chemistry and physics, in techniques varying from wet chemical etching to deep ion etching. Achieving nano-scale features with top-down techniques is controllable and verifiable with today's characterization techniques. This control and verification aspect is an integral part of top-down fabrication at the nano-scale. Characterization tools commonly used in top-down nanofabrication are discussed in this course in the context of process development and manufacturing. These tools include optical microscopies, electron and ion beam microscopies, spectroscopies, and scanning probe techniques.

**Prerequisite:** ESC 521.

Cross-listed with: NANO 522

ESC 523: Fabrication and Characterization for Bottom-up Nano-manufacturing

3 Credits

There are two broad approaches to fabrication and manufacturing at the nano-scale: bottom-up and top-down nanofabrication. These are complementary with the former having strong ties to biology and the latter having strong ties to traditional semiconductor processing. E SC 523 focuses on the bottom-up approaches, which provide an increasingly important alternative to top-down techniques. Bottom-up approaches to nano-scale fabrication mimic nature in harnessing fundamental chemical or physical forces operating at the nano-scale to assemble basic units into larger structures. The bottom-up, or self-assembly, techniques explored in this course cover material synthesis, structure fabrication, and material and structure characterization. The production of 0-D, 1-D, 2-D, and 3-D materials will be discussed and then the assembly of these materials into structures will be explored. Fabrication topics to be covered will include block co-polymer manipulation, vapor-liquid-solid growth, the Langmuir-Blodgett technique, surface functionalization, molecular self-assembly, DNA Origami, and bacterial and viral assembly. The characterization techniques to be covered will include those emerging tools capable of ultra-precise resolution such as tip-enhanced Raman scanning microscopy, scanning helium ion microscopy, and magnetic resonance sub-nanometer imaging.

**Prerequisite:** E SC 412, E SC 520, E SC 521

Cross-listed with: NANO 523

ESC 525: Neural Engineering: Fundamentals of Interfacing with Brain

3 Credits

Biophysical basis of neural function, measurable signals, and neural stimulations.

ESC 527: Brain Computer Interfaces (BCI)

3 Credits

Biophysical basis of non-invasive brain signals (electroencephalograms); real-time signal processing.

ESC 529: Neural Control Engineering

3 Credits

The ability to use formal control theory to observe and control neuronal systems is rapidly becoming more feasible as our models of neural systems become more realistic and as our advances in nonlinear Kalman filtering become more sophisticated. This course will explore the cutting edge of nonlinear state estimation of neuronal systems and the construction of control algorithms based on that state estimation. We will give an overview of several canonical neuroscience models, which represent experimental systems that can be controlled: the Hodgkin-Huxley equations, their reduction with the Fitzhugh-Nagumo equations, the Wilson-Cowan model of cortex, and recent models of Parkinson's disease. We will then apply nonlinear state estimation to measurements from such systems and construct control algorithms that interact with such models.

**RECOMMENDED PREPARATIONS:** Students without a background including calculus, differential equations, and linear algebra should consult with the instructor.

ESC 531: Neuroethics: Science, Technology, and Society

3 Credits

This course provides a close examination into the field of neuroethics and the responsible application of advances in neuroscience research and neuroengineering. Neuroethics is a relatively young and interdisciplinary field of inquiry that aims to be a platform for different stakeholders, including neuroscientists, clinicians, lawyers, engineers, policy makers and the general public to discuss the future of neuroscience and the different applications of neurotechnologies. Neuroethics is a field that brings normative, descriptive, theoretical and practical considerations at the table. This course will cover topics such as different perspectives on neuroethics, its scope and role in recent brain initiatives, ethical and societal implications of brain imaging for medical and non-medical purposes, ethical and societal implications of the use of pharmacological and neuromodulation interventions on the brain, uses of neuromodifiers for enhancement purposes, issues around personhood and other emerging topics relevant to neuroethics. Among the ethical issues examined in the course are issues related to mental privacy, safety considerations, responsibility, agency, and social justice.

**Recommended Preparation:** An understanding of ethics, societal implications of technology, and neuroscience or neurotechnology background. Courses in functional and integrative neuroscience, as well as courses that provide a grounding in bioethics

ESC 534: Advanced Solidification Processes in Metallic Materials

3 Credits

The emergence of advanced manufacturing processes, such as additive manufacturing, has introduced high levels of uncertainty in well-established process - structure - property- performance relationships. A comprehensive understanding of solidification across spatial and temporal scales is needed in order to identify the underlying phenomena

driving these unique structures and properties. In this course, the processes driving solidification and the properties of liquid metals will be covered to provide a framework for understanding more complex solidification processes in multi-component systems. Building on a fundamental understanding of both the thermodynamics and kinetics of solidification processes, the properties of interfaces and nucleation and growth will be studied across a range of material systems, including those exhibiting eutectic and peritectic transformations. With this basic knowledge, the role of complex processing conditions and their impact on multi-component alloy systems will be investigated for conditions prevalent in advanced manufacturing processes and correlated with advanced and emerging characterization tools.

**Recommended Preparation:** Students in this course should have a basic understanding (undergraduate level) of physical metallurgy principles, including solidification, solid-state phase transformations, heat treatment, and thermomechanical processing.  
Cross-listed with: MATSE 534

#### ESC 536: Wave Propagation and Scattering

4 Credits

Survey of analytical and numerical methods for solving acoustic, electromagnetic and elastic wave propagation and scattering problems.

**Prerequisite:** E MCH524A or E MCH524B

#### ESC 537: Multiple Scattering Theories and Dynamic Properties of Composite Materials

3 Credits

Acoustic, dielectric, elastic dynamic properties; periodic, random composites; wave propagation and scattering; attenuation, dispersion; super- viscous absorption; sonar, optical, ultrasonic applications.

#### ESC 540: Laser Optics Fundamentals

3 Credits

Selected topics in optics and laser physics, and their application in laser-materials processing. E SC 540 Laser Optics Fundamentals (3) Over the past two decades, new technologies such as laser-materials processing have moved from laboratory research to commercial applications. Engineers must now understand and apply many concepts of physics that in the past lay outside the boundaries of engineering. This course is intended for graduate students and practicing engineers whose exposure to physics has been limited to two or three undergraduate courses. It summarizes theories of geometric optics, physical optics, quantum optics and laser physics relevant to laser-materials processing, and it is designed to bridge the gap between abstract concepts and applications. Upon completion of this course, students will have developed sufficient proficiency in these theories to understand the intricacies of their use and application in laser-materials processing as described in the current technical literature. The student's accomplishment will be evaluated by mid-semester and final examinations. E SC 540 will be offered each fall semester. Classes will meet twice a per week; each class will be 75 minutes long. The enrollment for this course is anticipated to be 15 to 30 students.

#### ESC 541: Laser-Materials Interactions

3 Credits

Laser beam interactions with metallic, ceramic, polymeric and biological materials; effects of wavelength, power, spatial and temporal distributions of intensity. E SC 541 Laser-Materials Interactions (3) This course covers laser beam interactions with metals, insulators, semiconductors, polymers and biological materials relevant to laser-materials processing, and is designed to bridge the gap between abstract concepts and applications. Interactions such as heat flow, thermal stresses, melting, material removal, property changes and plasma effects are related to laser characteristics such as wavelength, power and the spatial and temporal distribution of intensity. Upon completion of this course the student will have developed sufficient knowledge of laser-materials interactions to understand their application in the current technical literature on laser-materials processing. The student's accomplishments will be evaluated by mid-semester and final examinations. This course will be offered each year in the spring semester. The class will meet once a week; each class period will be 150 minutes long. The enrollment for the course is anticipated to be 15-30.

#### ESC 542: Laser-Integrated Manufacturing

3 Credits

Integration of lasers into manufacturing processes: laser-assisted surface modifications; laser joining; laser-based material shaping processes. E SC 542 Laser-Integrated Manufacturing (3) E SC 542 is intended for graduate students and practicing engineers who have completed E SC 540 and E SC 541. It utilizes classroom lectures to provide a basis for students to develop an understanding of the integration of laser systems into manufacturing processes. Various lasers applicable to macro-processing, optical systems and manipulation components are discussed in terms of integration for industrial processing of materials, which include laser-assisted surface modification, laser joining and laser-based material removal processes. The unique characteristics and attributes of laser processing are discussed and contrasted with other contemporary manufacturing processes. Students will participate in a group project to develop and design an integrated system for selected laser manufacturing processes. Upon completion of this course, the student will understand the system requirements for laser-based manufacturing processes in terms of processing capabilities, equipment capabilities, safety requirements and economic considerations. This course will be offered each year in the fall semester. Classes will meet once per week; each meeting period will be 150 minutes long.

**Prerequisite:** E SC 540

#### ESC 543: Laser Microprocessing

3 Credits

Laser microprocessing of engineered and biological materials for electronic, opto-electronic, MEMS and medical/therapeutic applications. E SC 543 Laser Microprocessing (3) This course is intended for graduate students and practicing engineers who have completed E SC 540 and E SC 541. It covers laser processing to produce features and modify properties in metals, organic polymers, inorganic insulators, superconductors, semiconductors and biological materials on the meso, micro and nano scales. The lectures comprise analysis and discussion of selected technical papers on the use of laser microprocessing in electronic, opto-electronic, MEMs and medical-therapeutic applications.



Upon completion of this course, the student will have developed sufficient knowledge of laser microprocessing to understand its applications as described in the current technical literature. This course will be offered each year in the spring semester. Classes will meet once per week; each class period will be 150 minutes long.

**Prerequisite:** E SC 540

ESC 544: Laser Laboratory

3 Credits

Laser systems for materials processing, safety, critical processing parameters, diagnostic measurements, automation, sensing and control. E SC 544 Laser Laboratory (3) This course is intended for graduate students and practicing engineers who have completed E SC 540 and E SC 541. It covers laser systems for materials processing such as carbon dioxide, neodymium-YAG and ultraviolet laser systems; safety; identification of critical process parameters; measurement of spatial and temporal distributions of intensity, power, polarization, absorptivity and reflectivity; beam and work piece manipulators; automation' methods of sensing and process control. Students will attend lectures, observe demonstrations and perform hands-on measurements. Upon completion of this course, the student will have developed sufficient proficiency in laser techniques to perform them safely in a laboratory setting and to understand the intricacies of their use as described in the current technical literature on laser-materials processing. The student's accomplishment is evaluated by laboratory reports and a final examination. This course will be offered each summer.

**Prerequisite:** E SC 540

ESC 545: Engineering and Scientific Principles of Additive Manufacturing

4 Credits

In additive manufacturing (AM), components are fabricated via sequential joining using a bonding agent, curing, sintering, or fusing. AM fabrication of metals, ceramics, polymers, and organics has been demonstrated and is actively being used in industry and academia. ESC 545 / AMD 545 explores these processes with a focus on the fundamentals of sintering and fusion of metals, ceramics, and polymers. The topic is multi-disciplinary, requiring examination of individual AM system components, the physics of energy-material interactions, and the materials science at play during heat-reheat cycles. Opportunities for process sensing and real-time control are explored, as well as the role of post-process technologies in realizing serviceable components. These topics will lead to a discussion of methods and strategies to optimize component properties and characteristics. Current and potential impacts of AM on society are also covered.

**Recommended preparations:** A course in engineering materials and/or engineering analysis is highly desired but not required.

ESC 546: Advanced Metallic Material Feedstocks for Additive Manufacturing

4 Credits

Additive manufacturing (AM) processes use a variety of metallic material forms to produce complex components. These material forms can vary from metallic powders with a rather wide range of size distributions to metal wire to sheet and other more complex composite material types. Knowledge of the processing of these different feedstock forms along with means to characterize them is needed to develop AM processes

and procedures capable of being more widely used, particularly in critical applications. In this course, the production, handling, blending, and characterization of common metallic and composite feedstock materials will be covered. Feedstock forms to be addressed include metal and metal-ceramic composite powders, wire, and sheets, along with new product forms becoming available. A multi-disciplinary approach will be taken to elucidate the connections between production, characterization, and handling to develop an understanding of the role of feedstocks on the resulting process-structure-property relationships for AM processes and products.

**Prerequisite:** ESC 545 CONCURRENTS: MATSE 567, IE 527

ESC 550: Power Semiconductor Devices

3 Credits

Power electronic devices: Physics of operation, materials, architectural design, processing, reliability of operations, reliability with applications and challenges. E SC 550 Power Semiconductor Devices (3) The design and operation, of the emerging transformative power semiconductor devices, is founded on basic quantum mechanics and solid state physics principles. Power Semiconductor Devices, PSDs, handle high currents, high voltages and operate at high temperatures. Consequently, PSDs are complex in design, and challenging in long-term reliability. We study the fundamentals of PSDs architecture, processing, reliability, materials and characterization. We study Schottky- and P-i-N- rectifiers, the low power range MOSFETs transistors, the middle power range IGBT transistors, and high power range Thyristors. It is estimated that more than 50% of world electricity passes through power semiconductor devices; hence, optimizing the performance and reliability of these emerging power devices coupled with advancing power materials processing may lead to significant future energy savings. The subject matter is appropriate to students of physical sciences, electrical and materials engineering; in addition to broadening their knowledge base, it exposes them to this frontier research area and a new career-path option.

ESC 551: High Power Energy Storage

3 Credits

High-power energy storage technologies including advanced batteries, ultracapacitors, and flywheels. E SC (M E) 551 High Power Energy Storage (3) The course focuses on high-power, in-vehicle energy storage technologies used in hybrid electric vehicles, including advanced batteries, fuel cells, ultracapacitors, and flywheels. An interdisciplinary approach with mechanical, materials, electrical, and chemistry-based concepts provides the foundation to understand the operation and application of these energy storage devices. The course provides a synopsis of hybrid electric and fuel cell vehicle design, control, and simulation to determine the effect of energy storage components on performance and fuel efficiency.

Cross-listed with: ME 551

ESC 555: Neuroscience Data Analysis

3 Credits

Modern methods for the analysis of neural data. E SC 555 Neuroscience Data Analysis (3) Modern neuroscience experimental methods can generate enormous amounts of complicated data, and a wealth of techniques has sprung up drawing from a wide variety of fields to analyze it. In this course, students will learn how to utilize a toolbox of mathematical and computational techniques to analyze

electrophysiological, optical and anatomical data. This course will cover the biophysical origin and measurement of brain signals, as well as the theoretical background of modern analysis methods and their practical implementation. Topics covered include spectral methods, neural encoding and decoding, information theory and image analysis.

**Prerequisite:** Prerequisite or concurrent: BIOL 469 or equivalent

ESC 562: Solid State Phase Transformations in Metallic Materials

3 Credits

Metallic material systems or alloys are used across a wide range of applications. In order to obtain the desired properties, these materials are subjected to a range of thermo-mechanical processing steps and post-processing heat treatments which drive phase transformations while the material is in the solid state. The mechanisms of these solid-state phase transformations involve a wide range of fundamental materials science concepts, including crystallography, nucleation, grain growth, and diffusion. Practitioners must have knowledge across a range of materials disciplines, including thermodynamics, kinetics, and crystallography, in order to synthesize and capture the complex processes occurring over a wide range of spatial and temporal scales. Knowledge of these fundamental concepts along with their interactions over a range of length scales is applicable across a range of conventional and emerging materials processing fields, from primary steelmaking through heat treatment of nickel and aluminum-base alloys through the additive manufacturing of a wide range of advanced materials. In this course, a comprehensive study of solid state phase transformations in metallic materials will be undertaken. Beginning with the underlying crystal structures prominent in common alloy systems, the role of diffusion and nucleation and grain growth will be undertaken to describe the early stages of phase transformations. The resulting interfaces between different phases will be investigated along with the orientation relationships and the development of equilibrium precipitate morphologies. Building on solid state nucleation theory, microstructural development and precipitation and growth of secondary phases in both equilibrium and non-equilibrium conditions will be studied, to include common invariant transformations as well as spinodal decomposition, order-disorder transformations, and the formation of bainite and martensite. These fundamental materials processes will then be investigated for conditions prevalent in advanced manufacturing processes and correlated with advanced and emerging characterization tools.

**Recommend Preparation:** A basic understanding of solidification, solid-state phase transformations, heat treatment, and thermomechanical processing, such as MATSE 259, EMCH 211, and EMCH 213. MATSE 410, 425, 427, or equivalent is preferred but not require

ESC 577: Engineered Thin Films

3 Credits

Broad overview of the preparation-characterization-property relations for thin films used in a wide range of industrial applications.

**Prerequisite:** MATH 251 , PHYS 237

ESC 581: Microelectromechanical Systems/Smart Structures

3 Credits

Methods of micromachining, smart structure fabrication. Design, modeling for physical, chemical, biomedical microsensors/actuators. Smart structures and microsystems packaging/integration.

**Prerequisite:** E SC 414M

ESC 582: Micro- and Nano-Structured Light Emitting Devices

3 Credits

Principles and applications of Micro- and Nano-Structured Light Emitting Devices.

ESC 583: Micro- and Nano-Optoelectronic Devices and Applications

3 Credits

Principles and applications of micro- and nano-optoelectronic devices.

ESC 584: Bioarchitecture

3 Credits

Fundamentals of biological architecture observed in nature with emphasis on symmetry and topology with examples from recent literature. Bioarchitecture is the use and implementation of concepts and principles from nature to design functional materials, devices, and systems. Inspired by the structure and utility of biological surfaces, various surfaces have been engineered with micro- and nanoscale features. Bio-derived materials hold great promise to provide a broad range of industrial solutions. These materials can be shaped into various geometries such as fibers, colloids, and thin films. Recombinant expression or direct extraction of bio-derived materials from biological organisms can provide a new generation of recyclable-engineered materials. Understanding the structures and functional characteristics of biological architecture will expedite the design, fabrication, and synthesis of eco-friendly, recyclable, advanced materials, with novel physical properties.

ESC 596: Individual Studies

1-9 Credits/Maximum of 9

Creative projects, including nonthesis research, which are supervised on an individual basis and which fall outside the scope of formal courses.

ESC 597: Special Topics

1-9 Credits/Maximum of 9

Formal courses given on a topical or special interest subject which may be offered infrequently.

ESC 600: Thesis Research

1-15 Credits/Maximum of 999

No description.

ESC 601: Ph.D. Dissertation Full-Time

0 Credits/Maximum of 999

No description.

ESC 602: Supervised Experience in College Teaching

1-3 Credits/Maximum of 6

No description.

Cross-listed with: EMCH 602

ESC 610: Thesis Research Off Campus

1-15 Credits/Maximum of 999

No description.

ESC 611: Ph.D. Dissertation Part-Time

0 Credits/Maximum of 999

No description.