A Cross-Disciplinary Graduate Degree Concentration in Nanotechnology at Stevens Institute of Technology

by

Faculty Working Group on Nanotechnology Graduate Education

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Nanotechnology as Defined by the National Nanotechnology Initiative

Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1-100 nanometer range

Creating and using structures, devices and systems that have novel properties and functions because of their small and/or intermediate size

Ability to control or manipulate on the atomic scale

Background and Motivation

National Science Board's 2020 Vision for NSF (draft) stipulates that *"The National Science Foundation ensures that the Nation maintains a position of eminence in global science, technology and knowledge development, through leadership in transformational research and excellence in science education, thus driving economic vitality, an improved quality of life, and national security."* Nanotechnology is undoubtedly at the forefront of transformational research that will enable breakthrough and field-changing advancement in science and technology spanning a broad spectrum of engineering and science disciplines.

Indeed, the last decade has witnessed a phenomenal growth in research investment in nanotechnology by federal agencies such as NSF, DARPA, and NIH. Nanotechnology will be the growth engine for R&D for decades to come, with investment growth increasingly at the expense of traditional disciplinary domains. Market demand for professionals with advanced degree training relevant to nanotechnology will be fueled by the permeation of new discoveries and applications into diverse sectors of the economy. Nanotechnology research is blossoming in a large number of universities, some with tens of million dollars of federal funding. Graduate degree and certificate programs in nanotechnology are now being offered at a small but increasing number of universities, including Duke, Penn State, Penn/Drexel, Rice University, Stanford, University of Minnesota, and University of Washington. A common trait of these programs is that they all involve many engineering and science disciplines and are championed by faculty with significant research interest in diverse areas of nanotechnology. In fact, cross-disciplinary collaboration is a necessity, not a luxury, for any nanotechnology graduate program to be successful due to the multidisciplinary nature of this field.

There has also been substantial growth in nanotechnology research at Stevens in the last several years. Faculty teams comprising members from various academic departments have joined force to successfully compete for federal funding in related areas. *Several interdisciplinary research focus areas with nanotechnology as a critical enabler have been developed or are emerging within the broad theme of Multi-Scale Engineering & Science at Stevens. These areas include Chemical and Biological Micro-Systems; Multi-Scale Design, Fabrication, and Manufacturing of Complex Structures and Composites; Controlled Release and Regenerative Medicine; Cell-Cell and Cell-Material Interactions; Nanoparticulates for Environmental Remediation; Quantum Electronic Structures and Devices; Nano-Photonic Sensing and Imagining; and Health and Environmental Impact of Nanomaterials.* The collaborative activities of faculty with complimentary expertise and capabilities and their drive for research excellence will accelerate the pace of externally funded research thus providing increased graduate nano-relevant research opportunities particularly at the doctoral level. Research growth in these areas will undoubtedly propel Stevens to a higher tier of national and international recognition.

Educational training for our graduate students has not been in step, however, with our research expansion as well as national trend in nanotechnology, as evidenced by very few relevant technical electives in Stevens' engineering and science graduate curricula. The absence of a solid nanotechnology component in our graduate education is not consistent with Stevens' growth strategy in research nor conducive to our competitiveness in the field of nanotechnology. An Institute-wide educational infrastructure is critically needed to support Stevens' research growth and to better prepare our graduate students, especially doctoral students, in burgeoning nanotechnology. In recognition of this need and with encouragement and guidance of Dean George Korfiatis, an interschool faculty working group was assembled last June to explore the merits and feasibility of a cross-cutting nanotechnology graduate program that unifies major engineering and science disciplines. This proposal is a culmination of a series of brain-storming discussions. The faculty working group concludes that an Institute-wide Graduate Degree Concentration in Nanotechnology (referred to as the Program thereafter) is in the strategic interest of the Institute. Critical contributions from many of our faculty colleagues have also made this proposal possible.

Vision and Mission

The faculty working group envisions *a vibrant interdisciplinary Program that provides stimulating and cross-fertilizing educational training in nanotechnology and contributes to as well as thrives from the Institute's research excellence in related frontiers while preserving strong disciplinary fundamentals*. The mission of the Program is to equip Stevens' graduate students in general, and doctoral students in specific, with an interdisciplinary intellectual capacity so as to excel and compete in the ever expanding world of nanotechnology. Through pooling complementary faculty expertise and resources, the Program aims to provide students, via a common core course and a range of technical electives, with the following attributes:

(1) The understanding of nanoscale phenomena and the familiarity with the techniques for characterization and measurements of structures and properties;

(2) The knowledge for synthesis, processing, and manufacturing of nano structures, nanocomponents, as well as multiscale systems with nano building blocks for applications ranging from life sciences to engineering;

(3) The ability to design, analyze and simulate nanostructures, nanocomponents, and nanodevices for various applications;

(4) The ability to excel in an interdisciplinary environment, to critically/creatively think, and to seize and develop commercial opportunities in the fast-advancing nanotechnology field.

Outcome and Benefits

The Program will lead to the establishment of the first graduate education platform that truly unifies and mutually benefits many engineering and science disciplines at Stevens. Tangible benefits include, but are not limited to:

(1) Availability of a stimulating and cross-fertilizing educational infrastructure for interdisciplinary graduate training to support and enhance Institute's research thrusts with nanotechnology as a key enabler;

(2) Enhancement of quality of Ph.D. education through increased choice of relevant technical electives for doctoral students who usually run out of course options within the first two years of their graduate studies, a common problem at Stevens;

(3) An exciting recruiting vehicle to attract and train high-quality, full- and part-time graduate students interested in nanotechnology;

(4) A strong foundation for interschool and interdepartmental faculty partnership going beyond nanotechnology;

(5) Stevens with a notable and credible footprint and significantly improved competitiveness in major research and education funding opportunities in the nano arena.

Program Specifics

<u>Founding Departments and Program Committee</u>

The faculty working group proposes to establish an Institute-wide Graduate Degree Concentration in Nanotechnology. The Program will be interdisciplinary, the hallmark of nanotechnology, with faculty champions from various academic departments in SOE, ISSA and The Howe School. Founding departments of the Program are as follows. Other interested entities can be added anytime as warranted.

Department of Chemical, Biomedical, and Materials Engineering
Department of Chemistry and Chemical Biology
Department of Civil, Environmental, and Ocean Engineering
Department of Mechanical Engineering
Department of Physics and Engineering Physics

The inauguration Program Committee will consist of current members of the Faculty Working Group – Prof. Kurt Becker (PEP), Prof. Hong-Liang Cui (PEP), Prof. Henry Du (CBME), Prof. Frank Fisher (ME), Prof. Xiaoguang Meng (CEOE), Prof. Yong Shi (ME), Prof. Svetlana Sukhishvili (CCB), and Prof. Hongjun Wang (CBME). Replacement appointment may be made by Department Directors at any time. Program Committee Chair will be elected by the Program Committee. The responsibility of the Committee is to work with core faculty members to ensure timely and coordinated development and quality delivery of the nanotechnology curriculum.

Core Faculty Members

Core faculty members from the founding departments are key enablers of the Program. They are the providers and instructors of various core and elective courses in the nanotechnology curriculum, as part of their regular teaching responsibilities in their academic departments. Listed below are current core faculty members by departments, together with their *nano-relevant* research interests and expertise. Additional core faculty members will be added to the list as relevant courses are introduced to the curriculum.

Department of Chemical, Biomedical, and Materials Engineering:

Ron Besser, Professor of Chemical Engineering – *nano/micro-fabrication for microreactor technology*

Henry Du, Professor of Materials Engineering – *molecular and nano-scale surface modification and nanophotonic sensing and imaging*

Dilhan Kalyon, Professor of Chemical Engineering – *synthesis and fabrication of colloids, nanoparticles, and nanocomposites*

Suphan Koven, Professor of Chemical Engineering – *crystallization of nanopowders for energetics*

Niyi Lawal, Professor of Chemical Engineering – *microfluidic modeling and chemical synthesis using microreactors enabled by nanocatalytic surfaces*

Woo Lee, Professor of Materials Engineering – *multi-scale synthesis and fabrication of novel structures, chemical/biological microsystems*

Matt Libera, Professor of Materials Engineering – *cell-material interactions and electron beam-assisted fabrication of biologically active nano-/micro-arrays*

Hongjun Wang, Assistant Professor of Biomedical Engineering – *nanomedicine and biomaterials design, cell signaling*

Xiaojun Yu, Assistant Professor of Biomedical Engineering – *regenerative medicine and cell-cell interaction*

Department of Chemistry and Chemical Biology:

James Liang, Associate Professor of Chemistry and Chemical Biology – *synthesis and nanofabrication of drugs and biomaterial surfaces for controlled release*

Svetlana Sukhishvili, Associate Professor of Chemistry and Chemical Biology – *interfacial phenomena in polymers and biopolymers, controlled release, nanophotonic sensing*

Jiahua Xu, Associate Professor of Chemistry and Chemical Biology – *growth, differentiation, migration, invasion, and gene expression of cells and their dependence on organization and composition of extracellular matrix environment in mammalian tissues*

Department of Civil, Environmental, and Ocean Engineering:

Christos Christodoulatos, Professor of Environmental Engineering – *environmental behavior of nanoparticles and their use for water treatment*

Xiaoguang Meng, Associate Professor of Environmental Engineering – *science and technology of nanoparticulates for environmental remediation*

Mahmoud Wazne, Assistant Professor of Environmental Engineering – *nanomaterials for envrionmental remediation and its fate and transport*

X. Frank Xu, Assistant Professor of Civil Engineering – *computational mechanics at multi-length scales*

Department of Mechanical Engineering:

Frank Fisher, Assistant Professor of Mechanical Engineering – *nanocomposites and nanomechanics, bioinspired nanomaterials, nanosensors*

Yong Shi, Assistant Professor of Mechanical Engineering - *MEMS/NEMS design and fabrication, nanofibers and nanocomposites, smart structures*

Zhenqi Zhu, Associate Professor of Mechanical Engineering – *nano-precision actuators and nano-robotics*

Department of Physics and Engineering Physics:

Kurt Becker, Professor of Physics – *microplasma and modeling of plasma-surface interactions*

Hong-Liang Cui, Professor of Physics - *quantum electronic and optic devices, superlattices, theory and modeling of quantum structures, fiber optical sensors*

Rainer Martini, Assistant Professor of Physics - *semiconductor and semiconductor heterostructures for ultrafast switching, photonic sensing*

The Howe School:

Thomas Lechler, Associate Professor of Technology Management - *project management, innovation management, entrepreneurship, global innovation management*

Gary Lynn, Associate Professor of Technology Management – *emerging technology, marketing, entrepreneurship and new product development*

Program Options and Requirements

The Program offers the following degree options, Masters of Science, Masters of Engineering, and Doctor of Philosophy, all in nanotechnology concentration. Stevens' academic policy governing the awarding of advanced graduate degrees apply. To qualify for the nanotechnology concentration, in addition to satisfying disciplinary core requirements, candidates for Masters' degrees must complete the common core and a minimum of three elective courses and should attend regularly the seminar series in the nanotechnology curriculum. Thesis option is also available for Masters' degrees. Candidates for Ph.D. degrees in the nanotechnology concentration must satisfy disciplinary core requirements, must complete the common core and a minimum of five elective courses in the nanotechnology curriculum, and must attend the nanotechnology seminar series and related assignment. In addition, the Ph.D. candidates must successfully execute a doctoral dissertation in the realm of nanotechnology.

Admissions Requirements

Disciplinary admissions standards apply. Applications are processed and decisions are made at individual disciplinary levels.

Administrative Structure

The Program will be operated with utmost efficiency and minimum bureaucracy. To best coordinate this Institute-wide effort and to ensure availability of adequate resources especially at the infant stage, it is recommended that the Program be administered jointly by the Deans' Offices of SOE and ISSA with support from the Program Committee. It is further recommended that the Dean of Academic Administration be appointed to lead the Program.

The Nanotechnology Curriculum

Summarized in Table 1 are existing and proposed courses in the nanotechnology curriculum. Existing courses require significant content upgrading to bring them in the realm of nanotechnology. It is fully anticipated that more courses will be added to the curriculum as new faculty members with relevant expertise and interest are recruited and when other non-core faculty members develop and expand their capabilities in the area of nanotechnology. Course descriptions are included in Appendix A. Proposals for the new courses are attached in Appendix B.

Funding

Modest level of internal support is sought from the Institute to successfully launch the Program. The support will be used for marketing as well as for faculty course development effort in the summer should such effort during academic semesters unduly burden them as deemed by their Department Directors with proper time justifications. Center for Innovation in Engineering and Science Education (CIESE) may be a source of seed funding also. Once a steady state is achieved in the next two years, internal support will be limited to marketing the Program.

It is anticipated that the core faculty members, either as a whole or in sub-teams, will join force to aggressively seek federal funding by targeting all relevant and available grant proposal opportunities. One example is NSF's Integrative Graduate Research and Education Traineeship (IGERT) Program. The establishment of the Program will position Stevens well in funding competitiveness.

Table 1. Nanotechnology Curriculum by School or Department

From SOE & ISSA

1. Nanoscale Science and Technology (new, multi-instructors) – *common core*
2. Techniques of Surface and Nanostructure Characterization (semi-existing, multi-instructors)
3. Nanotechnology Seminar Series (organized and coordinated in conjunction with and as part of the seminar series of the founding academic departments)

From CBME

4. Fabrication Techniques for Micro and Nano Devices (semi-existing, Prof. Besser)
5. Microchemical Systems (Prof. Besser)
6. Bio/Nano Photonics (new, Prof. Du)
7. Colloids and Interfacial Phenomena at the Nanoscale (existing, Prof. Kalyon)
8. Nanoparticulate Synthesis, Processing and Applications (with lab) (new, Prof. Kalyon)
9. Nanocatalysis (new, Profs. Koven/Lawal)
10. Crystallization of Biological Molecules (new, Profs. Koven/Lawal)
11. Phase Transformation for Nanostructure Synthesis and Assembly (existing, Prof. Lee)
12. Nanomedicine (new, Prof. Wang)
13. Tissue Engineering (existing, Prof. Yu)
14. Nanobiotechnology (new, Prof. Yu)
15. Advanced Biomaterials (existing, Prof. Wang)

From CCB

16. Polymers at Solid-Liquid Interfaces (existing, Prof. Sukhishvili)
17. Polymer Functionality (existing, Prof. Liang)
18. Cellular Signal Transduction (existing, Prof. Xu)

From CEOE

19. Health and Environmental Effects of Nanotechnology (new, Profs. Meng & Wazne)
20. Multi-scale Computational Modeling in Mechanics (new, Prof. Xu)
21. Environmental Chemistry (existing, Prof. Christodoulatos)
22. Physicochemical Processes for Environmental Control (existing, Prof. Christodoulatos)

From ME

23. Mechanics at the Nano- and Micro-Scale (new, Prof. Fisher)
24. Design and Fabrication of Nano and Microelectromechanical Systems (new, Prof. Shi)
25. Multi-Scale System Design (new, Prof. Zhu)
26. Principles of Ultraprecision Engineering (new, Prof. Zhu)

From PEP

27. Physics and Applications of Semiconductor Nanostructures (existing, TBD)
28. The Physics of Nanostructures (existing, TBD)

From The Howe School

29. Entrepreneurship (existing, Prof. Lechler, Prof. Lynn)

Appendix A

Compiled in this appendix are course descriptions of existing and proposed courses in the nanotechnology curriculum listed in Table 1. All courses in the curriculum will be designated by prefix NANO, in addition to the designation of the offering discipline. For example, Mechanics at the Nano- and Micro-Scale will be identified as NANO/ME6XX. This convention serves two purposes, one to acknowledge the contributing discipline and the other to allow flexibility for other graduate students not opting for the Program. For courses involving multiple instructors from two or more disciplines, only NANO needs to be used. For instance, the common core course, Nanoscale Science and Technology, will be identified as NANO600. Note that appropriate course numbers for new courses will be provided by the contributing disciplines, whereas course numbers for existing courses will be preserved. In rare case of overlap under the NANO designation, adjustment will be made to course numbering.

Upgrading of existing courses and development of new courses will be closely coordinated with core faculty involved.

NANO600 Nanoscale Science and Technology

This course aims to introduce students to the fundamentals of unique properties of nanostructures, their synthesis, and applications such as electronics, photonics, robotics, biotechnology, and environmental technology. Specifically, via examples given in the frontier of nanotechnology research and development, students will be able to gain important insights into when and why size matters, how the materials properties can be engineered through size control, how various nanostructures can be made, and what are the opportunities and challenges in realizing the projected potential of nanotechnology in a broad spectrum of engineering and sciences, including life science.

NANO6XX Techniques of Surface and Nanostructure Characterization

Covered in this course are the fundamentals, instrumentation, and applications of common analytical tools for surface and nanostructure characterization. The students will acquire the knowledge necessary for the selection of most suitable techniques and for the interpretation of the resultant information relevant to surface science and nanotechnology.

NANO/MT6XX Bio/Nano Photonics

This course deals with the harnessing of light for biological and biomedical applications. A range of topic areas will be covered, including fundamentals of lasers and light-matter interactions in bio-relevant systems as well as common laser-based techniques for biosensing, medical imaging, and patient therapy. Emphasis will be given to the frontier of nanotechnology in biophotonic applications.

NANO/ChE/EE/MT/PEP596 Fabrication Techniques for Micro and Nano Devices

This course will survey the common themes of fabrication used in the formation of micro and nanoscale devices. Will give broad exposure to a number of methods to prepare the student for more detailed, in-depth exploration in later coursework and research experiences. Emphasis will be placed on processing techniques that continue to be indispensible independent of scale (for example, the so-called "top-down" processes lithography and etching) and to see how they interface with newer techniques necessitated by continual size reduction (for example, the "bottom-up" technique, self-assembly).

NANO/ChE702 Microchemical Systems

Microchemical devices possess microscale characteristic geometry and as a result display many attractive attributes for use in chemical process unit operations. The course is a survey of microchemical systems covering (1) phenomena underlying the behavior of microscale chemical devices, (2) important experimental devices that have been reported in the literature, (3) microfabrication methods used for microchemical systems, and (4) applications of microchemical systems to solve chemical engineering problems.

NANO/ChE682 Colloids and Interfacial Phenomena - with Nanotechnology

This course will cover fundamental aspects of interfacial phenomena of interest to chemists, biologists, materials scientists, and engineers. Topics include consequences of surface tension; intermolecular forces at interfaces; adsorption at liquid/liquid and liquid/solid interfaces; Dispersion forces; Phase diagrams and mesophases; Colloidal dispersions; and applications to nanotechnology

NANO/ChE685 Nanoparticulate Synthesis, Processing and Applications (with lab)

Applications of nanoparticles and case studies in pharmaceutical, composite, biomedical and energetics industries. This course focuses on synthesis of nanoparticles for pharmaceutical, biomedical, composites, energetics, and personal care applications; Manufacturing and safe-handling of nanoparticles will be treated. Stabilization of nanoparticles using surface coating, encapsulation, surfactants will be discussed. Further discussed will be the engineering of ultimate properties of nanocomposites through use of nanoparticles: electrical, magnetic, mechanical, permeability, bioactivity properties. The course will have a laboratory to allow the students to allow the students to synthesize nanoparticles, disperse them into various types of binders using twin screw extrusion, and study the resulting changes in the rheological behavior and mechanical and permeability properties.

NANO/ChE653 Nanocatalysis

Introduction to catalysis. Preparation, characterization, and the study of catalytic properties of metal and oxide-based nanostructures, and their applications in the chemical, pharmaceutical, and fine chemicals industries, and environmental remediation. Theoretical and modeling methods for elucidation of mechanisms of chemical reactions on nanocatalysts. Control of structural characteristics of nanocatalysts. Development and application of in-situ characterization techniques for nanocatalysts. Recent advances in electrocatalysis, and photocatalysis.

NANO/ChE615 Crystallization of Biological Molecules

This course aims to introduce the students to basic concepts of crystallization which apply both to biological and inorganic products. Applications will primarily be in the pharmaceuticals industry where crystallization is an important purification step in obtaining biological products such as antibiotics, amino acids, enzymes and proteins. Emphasis will be on polymorphism, purity and particle size distribution which are the most important considerations in crystallization of biological compounds. State of the art crystallization techniques in the pharmaceutical industry will also be discussed.

NANO/MT602 Phase Transformation Control for Nanostructure Synthesis and Assembly

This course will review and assess our current understanding for controlling phase transformation phenomena associated with synthesizing and assembling nanostructures as key building blocks for designing and producing next-generation biomedical, chemical, energy, and pharmaceutical devices and systems from a multiscale engineering perspective.

NANO/BME6XX Nanomedicine

This course provides a comprehensive introduction to the rapidly developing field of nanomedicine, and application of nanoscience and nanotechnology in medicine such as diagnosis, imaging and therapy, surgery and drug delivery. The content of this course will be mainly based on the summaries of current research and application for different biological and medical requirements, and a brief description of the design, synthesis and characterization will be included. In addition, it will emphasize cooperative learning approaches involving strong student participation with team assignments and will be supplemented with specified readings. It is expected that at the end of the course students will have a clear image about nanomedicine and its future prospects.

NANO/BME6XX Nanobiotechnology

This course describes the application of nano- and micro-fabrication methods to build tools for exploring the mysteries of biological systems. It is a graduate-level course that will cover the basics of biology and the principles and practice of nano- and micro-fabrication techniques with a focus on applications in biomedical and biological research.

NANO/BME602 Tissue Engineering

This course is designed to cover the important fundamentals and applications of tissue engineering as an emerging therapeutic approach to treat damaged or diseased tissues, with the focus in nanoscale applications. The topics covered will include tissue engineering strategies such as the design of novel biomaterials and cellular engineering strategies including gene therapy, drug delivery and cell seeding of natural and synthetic polymeric scaffolds. Recent advances and current problems associated with different tissue engineered constructs will be presented and discussed in the context of various patho-physiological conditions of comprised tissues.

NANO/BME650 Advanced Biomaterials

This course will deal with major classes of engineering materials, their principal properties and design requirements that serve as both the basis for materials selection as well as for the ongoing development of new materials. It focuses on materials whose use puts them in direct contact with physiological systems. It covers inflammatory response, thrombosis, infection and device failure. It also includes developing the fundamental materials science and engineering concepts underlying the structure-property relationships in both synthetic and natural polymers, metals and alloys and ceramics relevant to *in vivo* medical-device technology. A significant nanotechnology theme will be provided to highlight new and recent advancement of biomaterials for biomedical applications.

NANO/CH672 Polymers at Solid-Liquid Interfaces

In this course, we will present a unique combination of fundamentals of colloid and polymer science. The emphasis will be on solid-liquid interfaces, where this type of interdisciplinary knowledge is often lacking. The course is recommended to scientists and engineers dealing with household and cosmetic products, paints, biotechnology, polymer implants, biosensors, tissue engineering, bioactive coatings, drug delivery and the emerging technologies of analysis of biological fluids using microdevices.

NANO/CH674 Polymer Functionality

This course covers topics at the interface of polymer and biomedical sciences with a focus on problems where polymer has made a particularly strong contribution to biomedical sciences and pharmaceuticals. Topics covered include the biopolymer, biomaterials, nanotechnology, smart polymer and functional applications in biotechnology, tissue/cell engineering, biosensor, and drug delivery etc.

NANO/CH690 Cellular Signal Transduction

This course covers the mechanism and biological role of signal transduction in mammalian cells. Topics included are extracellular regulatory signals, intracellular signal transduction pathways, role of tissue context in the function of cellular regulation, and examples of biological processes controlled by specific signal transduction pathways.

NANO/EN6XX Health and Environmental Effects of Nanotechnology

This course discusses the environmental and public health aspects of nanotechnology applications, benefits and risks, interaction of nanoparticles with organic, inorganic, and biological systems, environmental exposure routes, applications for environmental remediation, fate and transport of nanoparticles, and ethical and legal issues.

NANO/CE7XX Multi-scale Computational Modeling in Mechanics

This graduate course will introduce the applications of multiscale theory and computational techniques in the fields of materials and mechanics. Students will obtain fundamental knowledge on homogenization methods and be exposed to various upscaling and multiscale techniques. The first half of the course will be focused on the homogenization theory and its physical concept of Representative Volume Element. In the second part more advanced topics on uncertainty quantification and scale-coupling will be addressed through multiscale finite element methods and stochastic methods. Students are expected to develop their own course projects based on their research interests and the topics learned from the course.

NANO/EN570 Environmental Chemistry

Principles of environmental reactions with emphasis on aquatic chemistry; reaction and phase equilibria; acid-base and carbonate systems; oxidation-reduction; colloids; organic contaminants classes, sources and fates; groundwater chemistry; atmospheric chemistry.

NANO/EN571 Physicochemical Processes for Environmental Control

A study of the chemical and physical operation involved in treatment of potable water, industrial process water and wastewater effluent; topics include chemical precipitation, coagulation, flocculation, sedimentation, filtration, disinfection, ion exchange, oxidation, adsorption, flotation and membrane processes. The enabling aspects of nanotechnology in the physicochemical processes are discussed. A physical-chemical treatment plant design project is an integral part of the course. The approach of unit operations and unit processes is stressed.

NANO/ME6XX Mechanics at the Nano- and Micro-Scale

This course exposes students to the impact of mechanics at the nano- and micro-scale with regards to developments in MEMS and nanotechnology; illustrates current technologies under development to enhance mechanical behavior of materials via nanotechnology; demonstrates how specific physical behavior and engineering design requirements change at these small length scale; provides examples of how the concepts of mechanics can be used, or appropriately adapted, to describe behavior at the nanoscale (i.e. polymer-based nanocomposites); describea the constitutive relations for advanced materials (shape memory materials, piezoelectric materials, etc) that may be exploited for MEMS-based devices; overviews experimental mechanics at the nano- and micro-scale; Demonstrates the cross-disciplinary intersections that exist between mechanics and other fields (materials science, chemistry, physics, computer science, etc).

NANO/ME6XX Design and Fabrication of Nano and Microelectromechanical Systems

To introduce the students to topics in the design, modeling and fabrication of nano and micro electromechanical systems. A goal throughout the course will be to develop a physical intuition for the fundamental phenomena at these small scales. The material covered will be broad and multidisciplinary including: review of nano and microelectromechanic systems, dimensional analysis and scaling, thermal transport, fluid dynamics, microelectrics, feedback control, noises and electromagnetism at the micro and nanoscales; the modeling of a variety of new MEMS/NEMS devices; and approaches beyond the continuum theory including stochastic and deterministic methods. The goal will be achieved through a combination of lectures, case studies, individual homework assignments, and design projects carried out in teams.

NANO/ME6XX Multi-Scale System Design

Macro, micro and nano-scale technologies rely on scale-specific performance models, design methods and fabrication processes which may be used to engineer machines within a limited range of size. The inherent incompatibility between engineering processes at different size scales leads to machines whose interactions with larger/smaller machines may be limited or impractical. This is troublesome as mechanical systems are often required to perform functions which are best achieved via combinations of different-scale machines. This course introduces scaling laws, incompatibility of multi-scale systems (MuSS), and teaches the methods and approaches for engineering multi-scale mechanical systems to ensure compatibility of macro, micro and nano-scale machines/components. This is a key to enabling broad utility of emerging nano and micro-scale machines in the "macro-scale world." Examples of multi-scale systems include precision instruments, nanomanipulators, fiber optics, nanorobotics, MEMS, various types of microcopes and other micro-nano assemblies.

NANO/ME6XX Principles of Ultraprecision Engineering

The design, manufacturing, control, and metrology of ultraprecision engineering systems are dominated by a set of engineering principles and take an integrated and systematic engineering approach. This course teaches the basic methodology and principles underlying the design and manufacture of high- and ultraprecision machinery, instruments, and MEMS/NEMS processing equipment.

NANO/PEP691 Physics and Applications of Semiconductor Nanostructures

This course is intended to introduce the concept of electronic energy band engineering for device applications. Topics to be covered are electronic energy bands, optical properties, electrical transport properties of multiple quantum wells, superlattices, quantum wires and quantum dots; mesoscopic systems, applications of such structures in various solid state devices, such as high electron mobility, resonant tunneling diodes and other negative differential conductance devices, double-heterojunction injection lasers, superlattice-based infrared detectors, electron-wave devices (wave guides, couplers, switching devices) and other novel concepts and ideas made possible by nano-fabrication technology. Fall semester. Typical text: M. Jaros, *Physics and Applications of Semiconductor Microstructures*; G. Bastard, *Wave Mechanics Applied to Semiconductor Heterostructures*. Prerequisite for the course is basic knowledge in quantum mechanics and solid state physics (at the levels of PEP 553, PEP 503).

NANO/PEP740 The Physics of Nanostructures

Progress in the technology of nanostructure growth; space and time scales; quantum confined systems; quantum wells, coupled wells and superlattices; quantum wires and quantum dots; electronic states; magnetic field effects; electron-phonon interaction; quantum transport in nanostructures: Kubo formalism, Butikker-Landau formalism; spectroscopy of quantum dots; Coulomb blockade, coupled dots and artificial molecules; weal localization; universal conductance fluctuations; phase-breaking time; theory of open quantum systems: fluctuation-dissipation theorem; applications to quantum transport in nanostructures.

MGT663 Entrepreneurship

In this course students will present their own start-up ideas and will create a business plan as part of a team. They will develop an understanding of entrepreneurship and innovation, and will learn how to plan, start and grow a business venture. The course will focus on the creation of new businesses based on emerging technologies, including analysis of successes in nanotechnology, software, electronic commerce, and consumer product companies. Students will have a chance to review actual business plans, watch a video as the entrepreneurs present their plan to real venture capitalists and venture investors and then see a follow-on video of what happened as the investors asked pointed, candid questions - sometimes stumping the team. The course is structured to teach students how to write a compelling business plan that will help them raise money and implement their strategy.

Appendix B

Proposals for new courses in the nanotechnology curriculum. The course proposals are provided by core faculty members indicated as the Department Point of Contact.

Proposed New Course

Title: Nanoscale Science and Technology

Program: A Cross-Disciplinary Graduate Degree Concentration in Nanotechnology

Catalog Description: This course deals with the fundamentals and applications of nanoscience and nanotechnology. Size-dependent phenomena, ways and means of designing and synthesizing nanostructures, and cutting-edging applications will be presented in an integrated and interdisciplinary manner.

Proposed Course # or Level: NANO600

Prerequisites: permission of the instructor.

Cross-listing: ____________________________ (show cross-listed course number(s)

Grading method: _✓_ ABCF ___ Pass/Fail ___ Other

Credits: _✓_ 3 credits ___ Other

For Graduate Credit _✓_ Yes ___ No ___ Not for Dept Majors ___ Other

Objective: To introduce students to the fundamentals of unique properties of nanostructures, their synthesis, and applications such as electronics, photonics, robotics, biotechnology, and environmental technology. Specifically, via examples given in the frontier of nanotechnology research and development, students will be able to gain important insights into when and why size matters, how the materials properties can be engineered through size control, how various nanostructures can be made, and what are the opportunities and challenges in realizing the projected potential of nanotechnology in a broad spectrum of engineering and sciences, including life science.

Syllabus

Definition of nanotechnology, nanoscale dimension and paradigm, overview of nanotechnology applications

Physical principles at the nanoscale; one-, two-, and three-dimensional nanostructures; quantum dots, nanowires, nanotubes, nanoslabs, and photonic nanocrystals and their properties

Nanoscale fabrications; top down approaches; nanolithorgraphy (spatial resolution of optical, deep ultraviolet, x-ray, electron beam, and ion-beam lithography; bottom up approaches; molecular architectures by supra-molecular and polymer self-assembly; colloidal chemistry and nanoparticles; molecular machines

Nanostructure characterization; measurements of electronic, magnetic, optical, and mechanical properties; determination of morphological, shape, size, and other characteristics of nanostructures

Nanoelectronics; quantum confinement of electrons; quantum electronics; quantum computing

Nanophotonics; nanoscale optical interactions; near-field optics and microscopy; plasmonics; photonic crystals

Nanostructures as mechanical and electromechanical components; nano-electromechanical systems (NEMS); nanorobotics; nanocomposites

Nanotechnology for the environment and impact on the environment
Nanobiotechnology and nanomedicine; bioderived and bioinspired nanomaterials and nanostructures; near-field imaging, nanoparticles for medical diagnostics and targeted therapy; nanoclinics

Textbook(s) or References: None. Handouts will be provided

Mode of Delivery _✓_ Class ___ Online ___ Modules ___ Other

Program/Department Ownership: Physics and Engineering Physics

When first offered: N/A

Department Point of Contact: Prof. Kurt Becker

Date approved by individual school curriculum committee: N/A

Proposed New Course

Title: Techniques of Surface and Nanostructure Characterizations

Program: A Cross-Disciplinary Graduate Degree Concentration in Nanotechnology

Catalog Description: This course deals with the principles, instrumentation, and use of analytical techniques for the measurements of dimension, structure, and properties at molecular-, nano-, and micro-scale. Capabilities and limitations of the various techniques will be discussed with state-of-the-art examples as case studies.

Proposed Course # or Level: NANO6XX

Prerequisites: None

Cross-listing: ____________________________(show cross-listed course number(s)

Grading method: _✓_ ABCF ___ Pass/Fail ___ Other

Credits: _✓_ 3 credits ___ Other

For Graduate Credit _✓_ Yes ___ No ___ Not for Dept Majors ___ Other

Objective: To introduce students to the fundamentals, instrumentation, and applications of common analytical tools for surface and nanostructure characterization. The students will acquire the knowledge necessary for the selection of most suitable techniques and for the interpretation of the resultant information relevant to surface science and nanotechnology.

Syllabus

General Introduction; Tools of the Trade
Electron Scattering; Low Energy Electron Diffraction
Scanning Electron Microscopy; Energy Dispersive X-ray Analysis
Transmission Electron Microscopy; Electron Energy Loss Spectroscopy
Auger Emission; Auger Electron Spectroscopy
Photoemission; X-Ray Photoelectron Spectroscopy
Atomic Force Microscopy
Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy
Fluorescence Spectroscopy
UV-Visible Absorption Spectroscopy
Near-field and con-focal optical microscopy
Adsorption Isotherm

Textbook(s) or References: None. Handouts will be provided

Mode of Delivery _✓_ Class ___ Online ___ Modules ___ Other

Program/Department Ownership: CBME

When first offered: N/A

Department Point of Contact: Prof. Henry Du

Date approved by individual school curriculum committee: N/A

Proposed New Course

Title: Bio/Nano Photonics

Program: A Cross-Disciplinary Graduate Degree Concentration in Nanotechnology

Catalog Description: This course deals with the principles of light interactions with biological- and biomedical-relevant systems. The enabling aspects of nanotechnology for advanced biosensing, medical diagnosis, and therapeutically treatment will be discussed.

Proposed Course # or Level: NANO6XX

Prerequisites: NANO600

Cross-listing: MT6XX (show cross-listed course number(s)

Grading method: _✓_ ABCF ___ Pass/Fail ___ Other

Credits: _✓_ 3 credits ___ Other

For Graduate Credit _✓_ Yes ___ No ___ Not for Dept Majors ___ Other

Objective: To introduce students to the harnessing of light for biological and biomedical applications. The students will acquire fundamentals of lasers and light-matter interactions in bio-relevant systems as well as gain knowledge of common laser-based techniques for biosensing, medical imaging, and patient therapy. Students will also be exposed to the frontier of nanotechnology in biophotonic applications.

Syllabus

Introduction & Historical Perspectives
Lasers and Nonlinear Optics
Light-Matter Interactions at Multiscale; Plasmonics
Basics of Biology
Principles, Techniques, and Applications of Bio Sensing and Imaging
Microarray Technology for Genomics and Proteomics
Laser Tweezers and Laser Scissors
Nanophotonics for biotechnology and nanomedicine

Textbook(s) or References:

Textbook: P.N. Prasa, "Introduction to Biophotonics," Wiley-Interscience, Hoboken, 2003

Reference: P.N. Prasa, "Nanophotonics," Wiley-Interscience, Hoboken, 2004;
Selected papers and articles in literature.

Mode of Delivery _✓_ Class ___ Online ___ Modules ___ Other

Program/Department Ownership: CBME

When first offered: N/A

Department Point of Contact: Prof. Henry Du

Date approved by individual school curriculum committee: N/A

Proposed New Course

Title: Fabrication Techniques for Micro and Nano Devices

Program: A Cross-Disciplinary Graduate Degree Concentration in Nanotechnology

Catalog Description: This course will survey the common themes of fabrication used in the formation of micro and nanoscale devices. Will give broad exposure to a number of methods to prepare the student for more detailed, in-depth exploration in later coursework and research experiences. Emphasis will be placed on processing techniques that continue to be indispensible independent of scale (for example, the so-called "top-down" processes lithography and etching) and to see how they interface with newer techniques necessitated by continual size reduction (for example, the "bottom-up" technique, self-assembly).

Proposed Course # or Level: NANO596

Prerequisites: permission of the instructor.

Cross-listing: ChE/EE/MT/PEP596 (show cross-listed course number(s)

Grading method: _✓__ ABCF ___ Pass/Fail ___ Other

Credits: _✓_ 3 credits ___ Other

For Graduate Credit _✓_ Yes ___ No ___ Not for Dept Majors ___ Other

Objective: While the rapid emergence of nanotechnology fabrication has shown value for integration with microscale platforms, which are formed using a mature technology, there are few sources where this information is integrated. This course will pull together critical readings in the literature with a recent text in order to introduce graduate students whose research involves micro- and/or nano-fabrication

Syllabus:

Overview of Fabrication and Device Applications of Microtechnology, Microelectronics, MEMS, Nanotechnology

Materials Science, Physics, and Chemistry for Micro/Nanotechnology

Top-Down Processing: Photolithography for Pattern Formation and Transfer

Top-Down Processing: Bulk and Surface Micromachining for Production of Two- and Three-Dimensional Device Architectures

Top-Down Processing: Material Removal and Formation by Dry Etching and Thin-Film Deposition

Top-Down Processing: Assembly and Interfacing of Micro/Nanosystems Bonding and Packaging

Top-Down Processing: Molecular Imprinting and Soft Lithography—Revolutionary Techniques Bypassing Traditional Micromachining with Multiscale Applications

Bottom-Up Processing: Self Organization and Assembly of Nanoscale Materials and Devices

Bottom-Up Processing: Synthesis of Bulk Nanomaterials (Condensation, Fluid-Phase Synthesis, Spinning), the Building Blocks of Nanodevices

Design, Testing, and Reliability of Micro and Nanodevices; Novel Microfabrication Approaches: LIGA, Precision Machining

Device Applications and Specific Fabrication Issues: Microelectronics, Nanoelectronics, Mechanical and Optical Microsystems

Device Applications and Specific Fabrication Issues: Microfluidics, Microchemical Systems

Device Applications and Specific Fabrication Issues: BioMEMS, Bionanodevices

Student Presentations

Textbooks: Madou, M., Fundamentals of Microfabrication, 2nd ed., CRC Press.
Other general textbook on Nanofabrication to be determined.

Mode of Delivery: _✓_ Class ___ Online ___ Modules ___ Other

Department Ownership: CBME

When first offered: N/A

Department Point of Contact: Prof. Ronald Besser

Date approved by individual school curriculum committee: N/A

Proposed New Course

Title: Microchemical Systems

Program: A Cross-Disciplinary Graduate Degree Concentration in Nanotechnology

Catalog Description: A survey of microchemical systems which are defined as microscale, fluidic systems which generally incorporate a chemical reaction aspect. The class will spend significant time discussing the phenomena underlying the behavior of microscale chemical devices, using many application examples as a basis. Applications will include gas, liquid, and multiphase catalytic reactions, heat exchange, micromixing, and others. Microfabrication techniques which are mostly unique to microchemical systems will also be discussed.

Proposed Course # or Level: NANO702

Prerequisites: graduate standing, familiarity with reaction engineering and transport phenomena at an undergraduate level.

Cross-listing: ChE702 (show cross-listed course number(s))

Grading method: _✓__ ABCF ___ Pass/Fail ___ Other

Credits: _✓_ 3 credits ___ Other

For Graduate Credit _✓_ Yes ___ No ___ Not for Dept Majors ___ Other

Objective: Microchemical systems, i.e., fluidic systems having characteristic geometry in the sub-millimeter range and which generally include a reaction component, represent a new paradigm in chemical processing. As such, the topic is not covered in existing textbooks found in the standard classes like transport phenomena, reactor engineering, and plant design. The course is intended to pull together readings in disparate literature articles and books (including a course text) on the subject and expose the student to the crucial underlying issues of microchemical systems as well as to survey many applications.

Syllabus:

I. Definitions/Advantages of Microreaction Technology
II. Microfabrication Techniques
III. Micromixing
IV. Micro Heat Exchangers
V. Microsystems for Separation and Analysis
VI. Microsystems for Liquid Phase Reactors
VII. Microsystems for Gas Phase Reactions
VIII. Microsystems for Gas/Liquid Reactions
IX. Soft Lithography
X. Microsystems for Energy Generation
XI. Microsystems for Catalyst Screening

Textbooks:

Microreactors, by W. Ehrfeld, V. Hessel, H. Lowe, Wiley-VCH, 2000.

Mode of Delivery: _✓_ Class ___ Online ___ Modules ___ Other

Department Ownership: CBME

When first offered: N/A

Department Point of Contact: Prof. Ronald Besser

Date approved by individual school curriculum committee: N/A

Proposed New Course

Title: Nanoparticulate Synthesis, Processing and Applications (with lab)

Program: A Cross-Disciplinary Graduate Degree Concentration in Nanotechnology

Catalog Description: Synthesis, processing and applications of nanoparticles and case studies in pharmaceutical, composite, biomedical and energetics industries. Manufacturing and safe-handling of nanoparticles will be treated. Stabilization of nanoparticles upon surface treatment will be discussed. Further discussed will be the engineering of ultimate properties of nanocomposites through use of nanoparticles: electrical, magnetic, mechanical, permeability, bioactivity properties. The course will have a laboratory to allow the students to synthesize nanoparticles, disperse them into various types of binders using twin screw extrusion, and study the resulting changes in the rheological behavior and mechanical and permeability properties.

Proposed Course # or Level: NANO685

Prerequisites: permission of the instructor

Cross-listing: ChE685 (show cross-listed course number(s)

Grading method: ✓ ABCF ___ Pass/Fail ___ Other

Credits: ✓ 3 credits ___ Other

For Graduate Credit: ✓ Yes ___ No ___ Not for Dept Majors ___ Other

Objective: The objective of the course is to provide a working, hands-on knowledge base for the synthesis, rheology, processing and processing/ultimate properties of nanoparticles. This is to be achieved through a strong laboratory sequence to supplement the lectures, which will allow the students to synthesize various types of nanoparticles (for example, nanohydroxyapatite), process tactoids into nanoparticles using twin screw extrusion technology (clay nanoparticles upon intercalation and exfoliation), prevent the formation of agglomerates of nanoparticles (nanoalumina) upon surface modification, analyze the viscoelastic materials functions of nanocomposites, control of the orientation distributions of nanoparticles (multi-walled C nanotubes in converging flow) and relate to electrical/magnetic and rheological percolation and permeability/mechanical properties upon shaping of the nanocomposites (example: determination of permeability of clay incorporated films prior to and upon formation of layered nanocomposites). A second objective of the course is to provide a survey of different types of nanoparticles currently in use and under development in various industries and the analysis of the requisite properties to achieve the intended functionalities of nanoparticles in various industries.

Syllabus

Safe handling of nanoparticles

Synthesis of nanoparticles (example: nanohydroxyapatite for tissue engineering applications)

Generation of nanoparticles from tactoids upon processing (example: nanoclays)

Surface properties and interfaces: General Concepts

Capillarity, Wetting and Spreading

Mixing and compounding of nanoparticles in batch and continuous processors

Introduction to viscoelasticity and linear behavior

Surface modification and stability (example: nanoalumina particles)

Rheological and electrical percolation (example: electrical percolation with C nanotubes)

Mechanical and permeability properties of nanocomposites (example: permeability of clay incorporated films)

Uses and applications of nanoparticles in various industries: case studies

Textbook: Course notes and laboratory notes will be distributed through the web

Mode of Delivery: ✓ Class ___ Online ___ Modules ___ Other

Program/Department Ownership: Chemical Engineering

When first offered: N/A

Department Point of Contact: Prof. Dilhan Kalyon

Date approved by individual school curriculum committee: N/A

Proposed New Course

Title: Nanocatalysis

Program: A Cross-Disciplinary Graduate Degree Concentration in Nanotechnology

Catalog Description: Preparation, characterization, and the study of catalytic properties of metal and oxide-based nanostructures, and their applications in the chemical, pharmaceutical, and fine chemicals industries, and environmental remediation. Theoretical and modeling methods for elucidation of mechanisms of chemical reactions on nanocatalysts. Control of structural characteristics of nanocatalysts. Development and application of in-situ characterization techniques for nanocatalysts. Recent advances in electrocatalysis, and photocatalysis.

Proposed Course # or Level: NANO653

Prerequisites: None

Cross-listing: ChE653 (show cross-listed course number(s)

Grading method: _✓_ ABCF ___ Pass/Fail ___ Other

Credits: _✓_ 3 credits ___ Other

For Graduate Credit _✓_ Yes ___ No ___ Not for Dept Majors ___ Other

Objective: In the chemical, pharmaceutical and fine chemical industries, catalysts are nanoparticles usually of active metals supported on oxide-based structures, and are traditionally used to facilitate chemical reactions. The catalyst particle size as well as its distribution on the support seems to play an important role in the product distribution for most chemical reactions. Nanotechnology deals with the manipulation and the making of materials at the atomic and molecular level, therefore its application in catalysis holds promise for the achievement of 100% selectivity for the desired product. This course will provide a fundamental understanding of catalysis at the nanoscale, the different synthesis and characterization methods of nanomaterials for catalysis, and recent industrial applications of nanocatalysis.

Syllabus

Catalysis and Nanoscience
Novel Catalytic Properties of Bimetallic Surface Nanostructures
Molecular Mixed-Metal Clusters as Precursors for Highly Active Supported Bimetallic Nanoparticles
Wet Chemical Synthesis of Nanoparticles
Roadmap to New Catalyst System: Palladium Nanoparticles
Multifunctional Catalysts for Singlewall Carbon Nanotube Synthesis
Pt-Based Electrocatalysts for Direct Methanol (Ethanol) Fuel Cells
Nanofunctionalized Microporous Catalysts
Structure-Reactivity Relationships in Mesoporous Solid Acid Catalysts

Mesoporous Materials as Catalyst Supports
Nanosized Zeolites and their composites
Characterization and Understanding of Nanomaterials for Catalysis
New Nanomaterials and Applications in Catalysis

Textbook(s) or References: Nanotechnology in Catalysis, Vols. 1 & 2, B. Zhou, S. Hermans, and G. A. Somorjai, Springer December 2003 ISBN 0306483238

Mode of Delivery _✓_ Class ___ Online ___ Modules ___ Other

Program/Department Ownership: Chemical Engineering

When first offered: N/A

Department Point of Contact: Prof. Adeniyi Lawal/Prof. Suphan Koven

Date approved by individual school curriculum committee: N/A

Proposed New Course

Title: Crystallization of Biological Molecules

Program: A Cross-Disciplinary Graduate Degree Concentration in Nanotechnology

Catalog Description: Solubility and supersaturation. Homogenous and heterogeneous nucleation and crystal growth. Particle size distribution and its measurement. Polymorphism and solvent effects in the crystallization of antibiotics, amino acids, enzymes and proteins. Control of particle size and purity in the crystallization of biological molecules. Crystallization techniques practiced in the pharmaceutical industry.

Proposed Course # or Level: NANO615

Prerequisites: None

Cross-listing: ChE615 (show cross-listed course number(s)

Grading method: _✓_ ABCF ___ Pass/Fail ___ Other

Credits: _✓_ 3 credits ___ Other

For Graduate Credit _✓_ Yes ___ No ___ Not for Dept Majors ___ Other

Objective: This course aims to introduce the students to basic concepts of crystallization which apply both to biological and inorganic products. Applications will primarily be in the pharmaceuticals industry where crystallization is an important purification step in obtaining biological products such as antibiotics, amino acids, enzymes and proteins. Emphasis will be on polymorphism, purity and particle size distribution which are the most important considerations in crystallization of biological compounds. State of the art crystallization techniques in the pharmaceutical industry will also be discussed.

Syllabus:

Solubility of organic molecules
Supersaturation and metastability
Solution properties for crystallization of biological molecules
Homogeneous and heterogeneous nucleation
Basic concepts of crystal growth and kinetics
Particle size distribution and its measurement
Mass and heat transport processes in crystallization
Crystallization of antibiotics, amino acids and lipids
Crystallization of enzymes and proteins
Polymorphism and solvent effects in the crystallization of biological molecules
Control of size in the crystallization of biological molecules
Purity consideration in the crystallization of biological molecules
Applications in the pharmaceutical industry

Textbook(s) or References: There is no textbook for this course. Notes will be distributed to the students for each class.

Mode of Delivery _✓_ Class ___ Online ___ Modules ___ Other

Program/Department Ownership: Chemical Engineering

When first offered: N/A

Department Point of Contact: Prof. Suphan Koven/Prof. Adeniyi Lawal

Date approved by individual school curriculum committee: N/A

Proposed New Course

Title: Nanomedicine

Program: A Cross-Disciplinary Graduate Degree Concentration in Nanotechnology

Catalog Description: This course will provide a comprehensive introduction to the rapidly developing field of nanomedicine, and discuss the application of nanoscience and nanotechnology in medicine such as in diagnosis, imaging and therapy, surgery and drug delivery.

Proposed Course # or Level: NANO6XX

Prerequisites: NANO600

Cross-listing: BME6XX (show cross-listed course number(s)

Grading method: _✓_ ABCF ___ Pass/Fail ___ Other

Credits: _✓_ 3 credits ___ Other

For Graduate Credit _✓_ Yes ___ No ___ Not for Dept Majors ___ Other

Objective: Nanotechnology is engineering and manufacturing at the nano/molecular scale, and the application of nanotechnology to medicine is called "nanomedicine". It is referred as the application of nanotechnology for treatment, diagnosis, monitoring, and control of human biological systems. This course is aimed to provide a comprehensive introduction to the rapidly developing field of nanomedicine, and application of nanoscience and nanotechnology in medicine. The content of this course will be mainly based on the summaries of current research and application for different biological and medical requirements, and a brief description of the design, synthesis and characterization will be included. In addition, it will emphasize cooperative learning approaches involving strong student participation with team assignments and will be supplemented with specified readings. It is expected that at the end of the course students will have a clear image about nanomedicine and its future prospects.

Syllabus

1. **Introduction to nanomedicine and course outline**
2. **Nanoparticle I:**Metallic nanoparticles and their medical applications (including gold, silver)
3. **Nanoparticle II:**Self-assembled nanoparticles and their medical application (liposomes, polymeric micelles, polyplexes/lipopolyplexes)
4. **Nanoparticle III:**Polymeric nanoparticles and the medical application (dendrimers, nanospheres, nanocrystals, magnetic nanoparticles)
5. **Nanoparticle IV:** Quantum dots and its application (also including other fluorescent nanospheres)
6. **Self-assembled scaffolds and the application** (nucleic acid lattices and scaffold, peptides/protein fibrous scaffold)

7. **Student presentation*** (10 min presentation and 2 min Q&A)
8. **Nanotubes /nanowires and the medical application** (also including buckminsterfullerenes)
9. **mid-term exam**
10. **Nanocoating and the medical application** (nanocapsule and electrostatic assembly)
11. **Biochips design and their medical application** (micro- and nano-chip)
12. **Other nanotechnology and their application in medicine** (nanodevices, nanoneedles, nanomotor/machine, cantilevers with functionalized tips, nanopore sequencing, nanosensors, nanobarcodes, biomembrane, nanobots, and so on)
13. **Biocompatibility in medical application of nanotechnology**
14. **final exam**

Textbook(s) or References: no textbook, but handout will be provided

Mode of Delivery: __X_ Class ___ Online ___ Modules ___ Other

Program/Department Ownership: CBME

When first offered: N/A

Department Point of Contact: Prof. Hongjun Wang

Date approved by individual school curriculum committee: N/A

Proposed New Course

Title: Nanobiotechnology

Program: A Cross-Disciplinary Graduate Degree Concentration in Nanotechnology

Catalog Description: This course describes the application of nano- and micro-fabrication methods to build tools for exploring the mysteries of biological systems. It is a graduate-level course that will cover the basics of biology and the principles and practice of nano- and micro-fabrication techniques with a focus on applications in biomedical and biological research.

Proposed Course # or Level: NANO6XX

Prerequisites: NANO600

Cross-listing: BME6XXX (show cross-listed course number(s)

Grading method: _✓__ ABCF ___ Pass/Fail ___ Other

Credits: _✓_ 3 credits ___ Other

For Graduate Credit _✓_ Yes ___ No ___ Not for Dept Majors ___ Other

Objective: To learn the fundamental principles, methods and applications of nanobiotechnoloy, and to provide a platform to facilitate communications and interdisciplinary collaborations amongst biologists and engineers.

Syllabus:
Introduction to the course and nanobiotechnology.
Review of basic biological concepts and biological problems.
Cellular mechanotransduction and application in nanotechnology.
Synthesis of cell structures.
Introduction to nano- and micro-fabrication.
Nanomaterials.
Mid-term Exam
Imaging molecular and cellular processes in the living body.
Application of nanotechnology for biomineralization and the related orthopaedic applications.
Fluidics and microfluidic devices for the study of chemotaxis
Carbon nanotubes and carbon nanofibers for intracellular applications
Micro- and nano-electromechanical systems in biomedical applications.
Nanotechnology in cancer diagnosis and therapy.
Student Presentations.

Textbooks:
No text book is assigned for this course. Lecture notes will be distributed in addition to current research articles.

Mode of Delivery _✓_ Class ___ Online ___ Modules ___ Other

Program/Department Ownership: CBME

When first offered: N/A

Department Point of Contact: Prof. Xiaojun Yu

Date approved by individual school curriculum committee: N/A

Proposed New Course

Title: Health and Environmental Effects of Nanotechnology

Program: A Cross-Disciplinary Graduate Degree Concentration in Nanotechnology

Catalog Description: This course discusses the environmental and public health aspects of nanotechnology applications, benefits and risks, interaction of nanoparticles with organic, inorganic, and biological systems, environmental exposure routes, applications for environmental remediation, fate and transport of nanoparticles, and ethical and legal issues.

Proposed Course # or Level: NANO6XX

Prerequisites: NANO600

Cross-listing: EN6XX (show cross-listed course number(s)

Grading method: _✓_ ABCF ___ Pass/Fail ___ Other

Credits: _✓_ 3 credits ___ Other

For Graduate Credit _✓_ Yes ___ No ___ Not for Dept Majors ___ Other

Objective: Although nanomaterials open new avenues for engineering systems, concerns exist over their potential adverse effects. Nanomaterials exhibit properties different from those produced at the micro-scale level therefore care should be taken to investigate the potential health and environmental effects in order to establish potential ecological and health risk that the release of these materials may pose. This course addresses the potential risks and benefits of nanomaterials by reviewing their impact on human health and the environment, their use for remediation application, the legal and ethical issues associated with their introduction to the market place, and nanomaterials waste minimization and sustainable development.

Syllabus:
Environmental overview
Survey and characterization of nanoparticles
Environmental exposure routes
Nano-cell interactions (cytotoxicology of nanoparticles)
Biomedical applications
Application of nanotechnology for environmental remediation
Fate and transport of nanomaterials
Health and hazard risk assessment
Regulation and commerce
Ethical and legal considerations
Sustainability and green manufacturing
Case studies
Future Trends

Textbooks: No text book is assigned for this course. Lecture notes will be distributed in addition to current research articles.

Mode of Delivery: _✓_ Class ___ Online ___ Modules ___ Other

Program/Department Ownership: CEOE

When first offered: N/A

Department Point of Contact: Prof. Mahmoud Wazne and Prof. Xiaoguang Meng

Date approved by individual school curriculum committee: N/A

Proposed New Course

Title: Multiscale Theory & Computations in Engineering Mechanics

Program: A Cross-Disciplinary Graduate Degree Concentration in Nanotechnology

Catalog Description: This graduate course will introduce the applications of multiscale theory and computational techniques in the fields of materials and mechanics. The first half of the course will be focused on homogenization theory and its physical concept of Representative Volume Element. In the second part more advanced topics on scale-coupling and uncertainty quantification and will be addressed through multiscale finite element methods and stochastic methods.

Proposed Course # or Level: NANO7XX

Prerequisites: permission of the instructor

Cross-listing: CE7XX (show cross-listed course number(s))

Grading method: _✓__ ABCF ___ Pass/Fail ___ Other

Credits: _✓__ 3 credits___ Other

For Graduate Credit: _✓__ Yes ___ No ___ Not for Dept Majors ___ Other

Objective: Students will obtain fundamental knowledge on homogenization methods and be exposed to various upscaling techniques and numerical multiscale methods. Students are expected to develop their own course projects based on their research interests and the topics learned from the course.

Syllabus

1. The Theory of Composites (3 lectures)
   - 1.1 Micro- and nano-mechanics in composites
   - 1.2 Statistical characterization of spatial heterogeneity
   - 1.3 Bounds on the properties of composites
   - 1.4 Representative Volume Element approach
   - 1.5 Fast Fourier Transform method
2. Homogenization Theory and Numerical Methods (3 lectures)
   - 2.1 Perturbation techniques and asymptotic expansions
   - 2.2 Homogenization of elliptic problems
   - 2.3 Unit cell model
   - 2.4 Numerical applications in mechanics
3. Multiscale Finite Element Methods (4 lectures)
   - 3.1 Galerkin finite element methods
   - 3.2 Stochastic finite element methods
   - 3.3 Multiscale finite element formulation
   - 3.4 Variational multiscale method

3.5 Other numerical multiscale methods

4. Random Media and Stochastic Homogenization (4 lectures)
   4.1 Characterization of random media
   4.2 Orthogonal decomposition of random media
   4.3 Stochastic Representative Volume Element
   4.4 Stochastic Galerkin method
   4.5 Numerical stochastic homogenization method
   4.6 Multiscale stochastic finite element method

Textbook(s) or References:

No text book is assigned for this course. Lecture notes will be distributed in addition to research journal articles.

Mode of Delivery: _✓_ Class ___ Online ___ Modules ___ Other

Program/Department Ownership: CEOE

When first offered: N/A

Department Point of Contact: Prof. Frank Xu

Date approved by individual school curriculum committee: N/A

Proposed New Course

Title: Mechanics at the Nano- and Microscale

Program: A Cross-Disciplinary Graduate Degree Concentration in Nanotechnology

Catalog Description: This course discusses mechanics at the nano- and microscale and its relationship to MEMS and nanotechnology. Methods covered include: traditional mechanics at the micro/nanoscale (top-down modeling), scaling of atomistic simulations to the nano/microscale (bottom-up modeling), and hierarchical and concurrent multiscale techniques. Experimental mechanics at these length scales will also be covered.

Proposed Course # or Level: NANO6XX

Prerequisites. Students should have a strong understanding of mechanics and materials at the undergraduate level. *This course is available to graduate students only.*

Cross-listing: ME6XX (show cross-listed course number(s)

Grading method: _✓__ ABCF ___ Pass/Fail ___ Other

Credits: _✓__ 3 credits ___ Other

For Graduate Credit: _✓_ Yes ___ No ___ Not for Dept Majors ___ Other

Objective: The objective of this class is to expose students to the impact of mechanics at the nano- and microscale and to illustrate the contribution of this field to recent developments in MEMS and nanotechnology. The course will identify how physical behavior and engineering design requirements change at these length scales, and demonstrate how interdisciplinary collaborations between mechanics and other fields (materials science, chemistry, physics, computer science) are necessary to appropriately model mechanics at this level. The advantages and limitations of various top-down, bottom-up, and multiscale modeling techniques will be presented and their applications demonstrated.

Syllabus:

- introduction to nanomaterials
- scaling of traditional mechanics to the micro- and nano-level (top-down modeling)
- computational chemistry and its application for nano-structures and materials (bottom-up modeling)
- multiscale techniques
- constitutive relationships for advanced materials for MEMS applications (shape memory materials, piezoelectric materials, etc)
- nanocomposites (particularly polymeric)
- experimental mechanics at the nano- and micro-scale

Textbook(s) or References:

Extensive use of course handouts and technical papers will be used. If appropriate, a textbook may be assigned for the class (or provided on reserve at the library). Potential texts include:

- A.N. Cleland (2003), Foundations of Nanomechanics (ISBN: 3-540-43661-8)
- T. Chuang (Ed.) et al (2005), Nanomechanics of Materials and Structures (ISBN: 1-402-03950-6)
- P. Ajayan (Ed.) et al (2003), Nanocomposite Science and Technology (ISBN: 3-527-30359-6)

Mode of Delivery: _✓__ Class ___ Online ___ Modules ___ Other

Program/Department Ownership: Mechanical Engineering

When First offered: N/A

Department Point of Contact: Prof. Frank Fisher

Date approved by individual school curriculum committee: N/A

Proposed New Course

Title: Design and Fabrication of Nano and Microelectromechanical Systems

Program: A Cross-Disciplinary Graduate Degree Concentration in Nanotechnology

Catalog Description: This course covers more advanced topics in the design, modeling and fabrication of nano and micro electromechanical systems. The materials will be broad and multidisciplinary including: review of nano and microelectromechanic systems, dimensional analysis and scaling, thermal, transport, fluids, microelectronics, feedback control, noises and electromagnetism at the micro and nanoscales; the modeling of a variety of new MEMS/NEMS devices; and approaches beyond the continuum mechanics theory. The goal will be achieved through a combination of lectures, case studies, individual homework assignments, and design projects carried out in teams.

Proposed Course # or Level: NANO6XX

Prerequisites: ME573

Cross-listing: ME6XX (show cross-listed course number(s)

Grading method: _✓__ ABCF ___ Pass/Fail ___ Other

Credits: _✓_ 3 credits ___ Other

For Graduate Credit _✓_ Yes ___ No ___ Not for Dept Majors ___ Other

Objective: Micro and nano electromechanical devices (MEMS/NEMS), such as pressure sensors, accelerometers, rate gyroscopes, and high frequency resonators, require knowlege of a broad range of disciplines, from microfabrication to mechanics to electromagnetism. A goal throughout the course will be to develop a physical intuition for the fundamental phenomena at these small scales, expose the students with a variety of domain knowledge and the tools necessary. Through team works, students will learn how to design a micro or nano system to meet a set of specifications using a realistic micro or nano fabrication process. Along the way, student exercises will develop skills in locating suitable information from libraries and electronic archives, visualization of structures created with micro/nano fabrication process sequences, creation of low-order dynamical device models, and insertion of those models into the simulation of a complete electronic measurement circuits.

Syllabus:

Intro to NEMS and MEMS

Micro fabrication process review

Nano fabrication process

Lumped Element Modeling and Dynamics

Continuum Mechanics and stochastic methods

Dissipation and thermal energy

Fluids and transport in fluids

Microelectronics

Feedback control

Noises

Packaging

Nano sensors and actuators

Case Study: Bio NEMS, High Q NEMS devices

Final Student Presentation

Textbooks:

S. Senture, *Microsystems Design*

Mode of Delivery: _✓__ Class ___ Online ___ Modules ___ Other

Program/Department Ownership: Mechanical Engineering

When First offered: N/A

Department Point of Contact: Prof. Yong Shi

Date approved by individual school curriculum committee: N/A

Proposed New Course

Title: Multi-Scale System Design

Program: A Cross-Disciplinary Graduate Degree Concentration in Nanotechnology

Catalog Description: This course discusses the characteristics and incompatibility of macro, micro and nano-scale systems and technologies, and the principles and approaches of interface design and multi-scale system engineering to ensure compatibility. Scaling laws, error budget, and metrology are also discussed. Examples of multi-scale systems used in the course include precision instruments, nanomanipulators, fiber optics, nanorobotics, MEMS, various types of microscopes and other micro-nano assemblies.

Proposed Course # or Level: NANO6XX

Prerequisites: permission of the instructor.

Cross-listing: ME6XX (show cross-listed course number(s)

Grading method: _✓__ ABCF ___ Pass/Fail ___ Other

Credits: _✓_ 3 credits ___ Other

For Graduate Credit _✓_ Yes ___ No ___ Not for Dept Majors ___ Other

Objective: Macro, micro and nano-scale technologies rely on scale-specific performance models, design methods and fabrication processes which may be used to engineer machines within a limited range of size. The inherent incompatibility between engineering processes at different size scales leads to machines whose interactions with larger/smaller machines may be limited or impractical. This is troublesome as mechanical systems are often required to perform functions which are best achieved via combinations of different-scale machines. This course introduces scaling laws, incompatibility of multi-scale systems (MuSS), and teaches the methods and approaches for engineering multi-scale mechanical systems to ensure compatibility of macro, micro and nano-scale machines/components. This is a key to enabling broad utility of emerging nano and micro-scale machines in the "macro-scale world." Examples of multi-scale systems include precision instruments, nanomanipulators, fiber optics, nanorobotics, MEMS, various types of microscopes and other micro-nano assemblies.

Syllabus:

Scaling Laws
- Physics of Scaling Laws
- Multi-scale systems in nature

Fundamental Principles
- MuSS Design Fundamentals and Methods
- Design Principles and Systems Design
- MuSS Manufacturing Issues

Macro/Meso-scales Components and Characteristics

Principles, Metrics and Types of Cross-scale Incompatibilities
Incompatibilities of Macro/Meso Parts with Micro/Nano Parts
Integrating Constraints on Macro/Meso-scale Parts

Micro-scale Components and Characteristics

Principles of Macro/Meso-scale and Micro-scale Part Integration
Incompatibilities of Micro Parts with Nano Parts
Micro-scale Part Errors and Implications for Integration

Nano-scale Components and Characteristics

Principles of nm-scale Physics which Govern Integration Incompatibility
Nano-scale Actuators, Structures and Sensors
Trasmissability of Nano-scale Errors to other Scales

Nominal and Statistical Error Budgets

Principles of Determinism, Accuracy, Repeatability
Kinematic Error Modeling of Rigid-flexible Systems
Nominal and Probabilitic System Error Modeling

Mechanical Interfaces for Cross-scale Alignment

Principles of Mechanical Constraint
Design of Rigid, Flexible and Rigid-flexible Constraint
Manufacturing and Assembly of Cross-scale Interfaces

Mechanisms for Inter-scale Motion

Principles of Mass, Momentum and Energy Incompatibility
Momentum Incompatibilities
Energy Incompatibilities

Complexity of MuSS

Uncertainty and Difficulty
Complexity
Functional Periodicity

Metrology

System Requirements
Components and Selection Process
Metrology-Machine Integration

Textbooks:

No text book is assigned for this course. Lecture notes will be distributed in addition to current research articles.

Reference:

*Taniguchi, N.**, Nanotechnology—Integrated Processing Systems for Ultra-Precision and Ultra-Fine Products**, ISBN: 0198562837, (New York: Oxford Science Publications, 1996)*

*Smith, S.T. and D.G. Chetwynd **Development in Nanotechnology Volume 2: Foundations of Ultraprecision Mechanism Design***
ISBN: 2881248403 (Gordon and Breach Science Publishers, 1992. Available through University of Toronto Press)

Selected papers and articles in literature.

Mode of Delivery: _✓__ Class ___ Online ___ Modules ___ Other

Program/Department Ownership: Mechanical Engineering

When First offered: N/A

Department Point of Contact: Prof. Zhenqi Zhu

Date approved by individual school curriculum committee: N/A

Proposed New Course

Title: Principles of Ultraprecision Engineering

Program: A Cross-Disciplinary Graduate Degree Concentration in Nanotechnology

Catalog Description: Ultraprecision engineering is the key science for manufacturing industry, as it cuts across all the major disciplines of manufacturing technology. It is concerned with the design, development, manufacture and measurement of components and systems as diverse as microsurgical device, precision weapons, micro-electronic devices or grinding machines and robotics; techniques ranging from scanning tunnelling microscopy, through diamond turning, to nanopositioning and manipulation. The course provides in-depth coverage of state-of-the-art technology and fundamental principles in ultraprecision engineering.

Proposed Course # or Level: NANO6XX

Prerequisites: permission of the instructor.

Cross-listing: ME6XX (show cross-listed course number(s)

Grading method: _✓__ ABCF ___ Pass/Fail ___ Other

Credits: _✓_ 3 credits ___ Other

For Graduate Credit _✓_ Yes ___ No ___ Not for Dept Majors ___ Other

Objective: The design, manufacturing, control, and metrology of ultraprecision engineering systems are dominated by a set of engineering principles and take an integrated and systematic engineering approach. This course teaches the basic methodology and principles underlying the design and manufacture of high- and ultraprecision machinery, instruments, and MEMS/NAMS processing equipment.

Syllabus:

Ultraprecision engineering: design, fabrication, control, and metrology
Axiom of minimum information.
Principle of functional independence.
Total design.
Elimination of clearance.
Abbe's principle.
Design for stiffness and minimized structure loop.
Minimization of thermal deformation.
Accurate motion.
Kinematic design.
Distortionless constraints.
Error budget and error correction.
Filtering.

The reduction principle.
Upper limit to machining precision.
Principle of element technology.
The concept of machining unit.
The copying principle.
The evolution principle.
The anisotropic principle.
Again Abbe's principle.
Work material.
Multi-pass machining.
In-situ machining.

Textbooks: H. Nakazawa, *Principles of Precision Engineering,* 1994, Oxford University Press.
Reference: A. H. Slocum, *Precision Machine Design*, 1992, Prentice-Hall
Selected papers and articles in literature.

Mode of Delivery: _✓_ Class ___ Online ___ Modules ___ Other

Program/Department Ownership: Mechanical Engineering

When First offered: N/A

Department Point of Contact: Prof. Zhenqi Zhu

Date approved by individual school curriculum committee: N/A