

UNIVERSITY SENATE
UNIVERSITY AT ALBANY
STATE UNIVERSITY OF NEW YORK

Introduced by: Graduate Academic Council

Date: December 2005

PROPOSAL TO AMEND Ph.D. & M.S. PROGRAMS
COLLEGE OF NANOSCALE SCIENCE & ENGINEERING

IT IS HEREBY PROPOSED THAT THE FOLLOWING BE ADOPTED:

1. That the University Senate approve the attached Proposal to Revise Existing Graduate Academic Programs in NanoScience & NanoEngineering as approved by the Graduate Academic Council.
2. That this proposal be forwarded to the President for approval.

State University of New York

Proposed Revision of Existing Graduate Academic Program

1) **Current SED classification:**

Campus: University at Albany – SUNY
Academic Unit: College of Nanoscale Science & Engineering (CNSE)
Name of program: Nanosciences & Nanoengineering
Award: Ph.D. & M.S.
SED Program codes: 28095 & 28096
HEGIS: Materials Engineering 0915
Certification/licensure: none

2) **Summary of and Rationale for Revision of Existing Graduate Academic Program in Nanosciences and Nanoengineering**

Summary of change:

It is proposed that the existing graduate program, Nanosciences and Nanoengineering, currently offering the degrees of Ph.D. and M.S. within the College of Nanoscale Science and Engineering, be revised. Specifically, it is proposed that the Science and Engineering components of the current program be separated into distinct Nanoscale Science and Nanoscale Engineering degree programs and that the current Nanoscience and Nanoengineering concentration areas be expanded in number and separated into formal tracks within the Nanoscale Science and Nanoscale Engineering degree programs. In addition, it is proposed to establish a unifying and cross-disciplinary “Foundations of Nanotechnology” course sequence to serve both the Nanoscale Science and Nanoscale Engineering programs and replace the current core-course sequence in the Nanoscience and Nanoengineering graduate degree program.

Rationale for change:

The University at Albany’s College of Nanoscale Science and Engineering – the nation’s first college in nanoscale science and technology – has evolved into an internationally recognized center for research in nanoscale science, nanoscale engineering, and nanotechnology due to its eminently successful model for collaboration between industry, government, and academia. From an initial enrollment of 10 graduate students in Nanosciences and Nanoengineering degree program in the inaugural Fall 2003 semester, CNSE has welcomed over 80 graduate students for the Fall 2005 semester. The substantial success of the Nanoengineering and Nanosciences degree program relies on the expectation that the University in general and the CNSE in particular will continue to perform the critical function of providing an education to our students of the highest quality equal or superior to that available in institutions of higher learning anywhere in the world.

The rapid expansion of the graduate student clientele served by the CNSE and the Nanoscience and Nanoengineering degree program has been accompanied by parallel increases in faculty, administrative and technical staff, and most notably, the CNSE’s research and development infrastructure and the associated portfolio of sponsored research programs. As the national and international leadership of the CNSE in the fields of Nanoscale Science and Nanoscale Engineering is advanced it is appropriate to further mature and expand the curricular offerings made available to its students. Consequently a revision in the CNSE curricular offerings has been advanced by the Faculty and Administration of the CNSE as part of their collective obligations to participate significantly in the initiation, development, and implementation of CNSE Educational, Research, Service and Outreach programs.

This revision in the CNSE curricular offerings also responds to the national and international need for the “...establishment of an infrastructure capable of educating and training an adequate number of researchers,

teachers, and technical workers in nanotechnology,” as recently noted by the President’s Council of Advisors on Science and Technology.¹

Likewise, the proposed changes will further enhance the interdisciplinary educational environment that our students must have if they are to develop into the leaders in the fields of nanotechnology. As noted by Uddin and Raj Chowdhury, “Nanotechnology is truly interdisciplinary. An interdisciplinary curriculum that encompasses a broad understanding of basic sciences intertwined with engineering sciences and information sciences pertinent to nanotechnology is essential.”² This is precisely in accord with the National Nanotechnology Initiative, which has declared that “a well-educated citizenry, skilled workforce, and a supporting infrastructure of instrumentation, equipment, and facilities are essential foundations of the NNI”.³ Our proposed curriculum revisions closely parallel this sentiment.

Rationale for Degree Separation: As noted above, one focus of the revision is a separation of the Science and Engineering components of the current Nanoscience and Nanoengineering program into distinct Nanoscale Science and Nanoscale Engineering degree programs. This bifurcation will formalize the distinction between science and engineering tracks incorporated into the current program and more effectively service the present and future CNSE graduate clientele. The Nanoscale Science program will provide the critical theoretical and experimental skill base and know-how for knowledge creation in the areas of nanoscale materials, structures, and architectures. The Nanoscale Engineering program will provide corresponding skill and expertise in the design, fabrication, and integration of nanoscale devices, structures, and systems for the development and deployment of emerging nanotechnologies. This revision reflects and is motivated by the significant increase in CNSE faculty in both the science and engineering fields and the unparalleled expansion of the CNSE research and development infrastructure. Equally important it reflects the dramatic expansion and selected maturation of fields within nanoscale science and nanoscale engineering disciplines and the pressing need for a highly skilled science and engineering workforce demanded by those disciplines in both the public and private sectors.

This initiative to provide separate degrees in Nanoscience and in Nanoengineering is in accord with current or emerging nanotechnology educational initiatives at major institutions including the University of Washington, Penn State University, and Rice University.

Rationale for Track Expansion: Accompanying the separation in Nanoscale Science and Nanoscale Engineering degree programs is a proposed expansion of the current Nanoscience and Nanoengineering concentration areas (*Molecular Materials and Architectures; Optoelectronic Materials, Architectures, and Devices; NanoSystems Sciences and Technologies; Thin Film Single and Multilayered Material Structures; Nanomaterials for Nanotechnology; Nanoscale Materials Modeling, Characterization, Analysis, and Metrology*) into fourteen formal tracks:

Proposed Nanoscale Science Tracks (see Appendix A for descriptions):

- *Molecular Materials and Architectures*
- *Optoelectronic Materials and Architectures*
- *Spintronic Materials and Architectures*
- *Ultra-Thin Film Single and Multilayered Nanomaterial Structures*
- *Nanomaterials for Nanotechnology*
- *Nanoscale Materials Characterization, Analysis, and Metrology*
- *Economic Impacts of Nanoscale Science and Engineering*

Proposed Nanoscale Engineering Tracks (see Appendix A for descriptions):

¹ The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel, pg 4, May 2005.

² Mahbub Uddin and A. Raj Chowdhury, “Nanotechnology Education,” Proceedings of the International Conference on Engineering Education, Oslo, Norway, 2001

³ Nanotechnology Technology Initiative: Leading to the Next Industrial Revolution (National Science and Technology Council, Maryland, September 1999).

- *Nanoelectronic Engineering and Technology*
- *Optoelectronics and Photonics Nanoengineering*
- *Spintronics Nanoengineering*
- *NanoSystem Engineering and Technology*
- *NanoEngineering in Energy & Environmental Technologies*
- *Nanolithography Engineering and Technology*
- *Nanobiology Engineering and Technology*

This expansion also reflects and is motivated by the significant increase in CNSE faculty in both the science and engineering fields and the unparalleled expansion of the CNSE research and development infrastructure. These tracks are essential to prepare CNSE graduates in the leading fields of nanoscale science & engineering and nanotechnology, in general. Their foundation is firmly rooted in the current Nanoscience and Nanoengineering program and their formulation represents the logical next step in curricular development for the students and faculty of the CNSE.

Note: The final proposed Nanoscale Science Track: ‘Economic Impacts of Nanoscale Science and Nanotechnology’ represents a cross-listing with curricular tracks currently under development within the Nanoeconomics Constellation of the CNSE.

Rationale for “Foundations of Nanotechnology” course sequence: Separation of the science and engineering components of the current CNSE degree offerings does not dilute the dedication of the CNSE faculty to a truly interdisciplinary academic experience. Nor does it ignore the overwhelming consensus among nanotechnology educators, researchers, and professionals that interdisciplinary is a keystone for successful nanoscale science and engineering education. Consequently, a unique and visionary “Foundations of Nanotechnology” course sequence is proposed to serve both the Nanoscale Science and Nanoscale Engineering programs and replace the current core-course sequence in the Nanoscience and Nanoengineering graduate degree programs.

“Foundations” represents a modular four-course sequence that has been specifically designed to provide the base scientific skill set required by the varied undergraduate backgrounds of students entering CNSE. The parallel and complementary modular platform of the “Foundations” sequence responds to the need for simultaneous CNSE course content delivery to students possessing undergraduate degrees in Physics, Chemistry, Materials Science, Mathematics, Biology, Chemical Engineering, Electrical Engineering, and Mechanical Engineering. The “Foundations” sequence serves an analogous role for practicing professionals in the fields of nanoscale science, engineering, and nanotechnology that have or plan to enroll in CNSE degree programs.

It is the firm belief of the CNSE Faculty that the proposed alterations in the current CNSE degree program will place CNSE at the forefront of nanoscale science, nanoscale engineering, and nanotechnology education and will allow our College to continue to be viewed as the leading innovator in the field.

The programs affected by this proposed change do not lead to certification in classroom teaching.

3) Curriculum outline of the current program and of the proposed revised curriculum:

I. Master's of Science (MS) in Nanoscience and Nanoengineering. Current requirements:

1. *CNSE coursework (18 credits): CNSE Courses as advised including twelve credits of thesis research (CNSE 699).*
2. *Concentration coursework (9 credits): Courses constituting a 3-course sequence selected from one of the following sets of courses:*
 - a. *ACHM 508, ACHM 520a, ACHM 520b, ACHM 525a, ACHM 525b, ACHM 526 or ACHM 561*
 - b. *APHY 510a, APHY 510b, APHY 519, APHY 532, APHY 560, APHY 562, or APHY 563*
 - c. *CNSE 501, CNSE 511, CNSE 512, CNSE 519, CNSE 525, CNSE 528 or CNSE 541*

3. *Seminar / External Courses (3 credits) as advised.*
4. *Completion of an original research project that represents a significant scientific contribution to one of the appropriate CNSE concentration areas that leads to the submission of an acceptable Master's thesis. If the student successfully completes an appropriate portion of the Ph.D. written qualifying examination, a master's research project can be substituted for the formal thesis.*

I.A Proposed revision to the M.S. in Nanoscience and Nanoengineering:

It is proposed to separate the M.S. degree program in Nanoscience and Nanoengineering into respective M.S. degree programs in Nanoscale Science and Nanoscale Engineering.

Revised requirements for M.S. in Nanoscale Science:

1. ***CNSE coursework (18 credits): Six credits as advised relevant to a CNSE Nanoscale Science Track and twelve credits of thesis research (CNSE 699).***
2. *Completion of 9 credits from the "Foundations of Nanotechnology" Course Sequence.*
3. ***Seminar/External Courses as advised (3 credits): unchanged from existing M.S. requirement.***
4. *Completion of an original research project that represents a significant scientific contribution to one of the appropriate CNSE Nanoscale Science Tracks that leads to the submission of an acceptable Master's thesis. If the student successfully completes an appropriate portion of the Ph.D. preliminary written examination, a master's research project report can be substituted for the formal thesis.*

I.B Proposed revision to the M.S. in Nanoscience and Nanoengineering:

Revised requirements for M.S. in Nanoscale Engineering:

1. ***CNSE coursework (18 credits): Six credits as advised relevant to a CNSE Nanoscale Engineering Track and twelve credits of thesis research (CNSE 699).***
2. *Completion of 9 credits from the "Foundations of Nanotechnology" Course Sequence.*
3. ***Seminar/External Courses as advised (3 credits): unchanged from existing M.S. requirement.***
4. *Completion of an original research project that represents a significant scientific contribution to one of the appropriate CNSE Nanoscale Engineering Tracks that leads to the submission of an acceptable Master's thesis. If the student successfully completes an appropriate portion of the Ph.D. preliminary written examination, a master's research project report can be substituted for the formal thesis.*

II. PhD in Nanosciences and Nanoengineering. Current Requirements:

1. *Students admitted with an appropriate Bachelor's degree shall complete 66 credit hours of academic coursework in partial fulfillment of the Ph.D. degree requirements:*
 - a. *36 credit hours in coursework at the 500 level or higher (including coursework in the student's area of concentration).*
 - b. *12 credit hours of seminar/external courses.*

- c. 18 credit hours of Ph.D. dissertation research.
 - d. Completion of a seven core-course sequence consisting of an appropriate subset of the following courses: CHM 520A, CHM 520B, CHM 525A, CHM 525B, CHM 526, CHM 535A, and CHM 561; or PHY 510A, PHY 510B, PHY 519, PHY 532, PHY 560, PHY 562, and PHY 563; or CNSE 501, CNSE 511, CNSE 512, CNSE 519, CNSE 525, CNSE 528 and CNSE 541. The core-course sequence is designed to accommodate multiple nanosciences student specialization channels, including Physics and Chemistry.
2. Students admitted with an appropriate Masters of Science degree shall complete 36 credit hours of academic coursework in partial fulfillment of the Ph.D. degree requirements:
 - a. 15 credit hours in coursework at the 500 level or higher (including coursework in the student's area of concentration).
 - b. 6 credit hours of seminar/external courses.
 - c. 15 credit hours of Ph.D. dissertation research.
 - d. Completion of the core-courses listed above for which the student did not receive course equivalency upon matriculation into the Ph.D. program.
3. Qualifying Written Examination for Formal Admission to the Ph.D. program: Admission to the CNSE Ph.D. program requires successful completion of a qualifying written examination covering materials nanoscience, nanoengineering and basic nanoscience applications. The exam will be offered yearly and must be passed within two attempts to maintain academic standing in the CNSE Ph.D. program.
4. Preliminary Oral Examination for completion of the Ph.D. degree: Normally, within 2 semesters of passing the qualifying written examination, students in the CNSE Ph.D. program must take and pass a preliminary oral examination relevant to a CNSE concentration area. Successful completion of the preliminary oral examination is determined by a five-member oral examination committee. This committee consists of at least three members of the CNSE faculty (including the student's advisor) and at least one outside member (University at Albany faculty outside CNSE, or CNSE research partner). Upon passing this examination the student advances to candidacy for the Ph.D.
5. Submission and successful defense of a formal Ph.D. Dissertation: Within one semester of passing the preliminary oral examination, the candidate must submit to his or her Ph.D. dissertation committee a proposal outlining an original NanoSciences/NanoEngineering research project constituting a Ph.D. dissertation. The candidate must describe the motivation and background for the dissertation; the critical milestones for completing relevant research tasks; and a statement of work outlining a

specific research plan. The five-person Ph.D. dissertation committee consists of at least three members of the CNSE faculty (including the candidate's advisor) and at least one outside member (University at Albany faculty outside the CNSE, or a CNSE research partner).

Upon timely completion of the Ph.D. dissertation research project the candidate prepares a dissertation and submits the final draft to the dissertation committee. The committee ascertains the suitability of the draft and recommends amendments which the candidate must complete before the final defense is scheduled. Once approved by the committee, permission is granted for the candidate to present and defend his dissertation in a public seminar.

6. *Ph.D. Publication Requirement: For successful completion of the Ph.D. degree requirements, students are also required to be the first author on a minimum of two scientific publications that have already been accepted for publication in recognized peer-reviewed technical journals that are related to the their concentration area.*

II.A Proposed revision to the Ph.D. in Nanoscience and Nanoengineering:

It is proposed to separate the Ph.D. degree program in Nanoscience and Nanoengineering into respective Ph.D. degree programs in Nanoscale Science and Nanoscale Engineering.

Revised requirements for Ph.D. in Nanoscale Science:

1. *Students admitted with an appropriate Bachelor's degree shall complete 60 credit hours of academic coursework in partial fulfillment of the Ph.D. degree requirements.*
 - 1a. *36 credit hours CNSE coursework at the 500 level or higher with the following provisions:*
 - 1.a.i. *Completion of the 12 credit hours (four-course) "Foundations of Nanotechnology" sequence.*
 - 1.a.ii. *Completion of at least 9 credit hours of 600 or higher level coursework as advised relevant to a CNSE Nanoscale Science Track.*
 - 1b. *9 credit hours of seminar/external courses.*
 - 1c. *15 credit hours of Ph.D. dissertation research.*
2. *Students admitted with an appropriate Masters of Science degree shall complete 36 credit hours of academic coursework in partial fulfillment of the Ph.D. degree requirements.*
 - 2.a. *15 credit hours CNSE coursework at the 500 level or higher with the following provisions:*
 - 2.a.i. *Completion of "Foundations of Nanotechnology" course sequence for which the student did not receive course equivalency upon matriculation into the Nanoscale Science Ph.D. program.*
 - 2.a.ii. ***Completion of at least 6 credits hours of 600 or higher level coursework as advised relevant to a CNSE Nanoscale Science Track.***
 - 2.b. *6 credit hours of seminar/external courses.*

- 2.c. 15 credit hours of Ph.D. dissertation research.
- 3. **Preliminary Written Examination for Formal Admission to the Nanoscale Science Ph.D. program:** Admission to the Nanoscale Science Ph.D. program requires successful completion of a preliminary written examination covering fundamental topics in Nanoscale Science. The exam will be offered yearly and must be passed within two attempts to maintain academic standing in the Nanoscale Science Ph.D. program.
- 4. **Preliminary Oral Examination for completion of the Nanoscale Science Ph.D. degree:** Normally, within 2 semesters of passing the preliminary written examination, students in the Nanoscale Science Ph.D. program must take and pass a preliminary oral examination relevant to a Nanoscale Science Track. Successful completion of the preliminary oral examination is determined by a five-member oral examination committee. This committee consists of at least three members of the CNSE faculty (including the student's advisor who serves as chair) and at least one outside member (University at Albany faculty outside CNSE, or CNSE research partner). Upon passing this examination the student advances to candidacy for the Nanoscale Science Ph.D.
- 5. **Submission and successful defense of a formal Ph.D. Dissertation:** unchanged from existing Ph.D. requirement.
- 6. **Ph.D. Publication Requirement:** unchanged from existing Ph.D. requirement.

II.B Proposed revision to the Ph.D. in Nanoscience and Nanoengineering:

Revised requirements for Ph.D. in Nanoscale Engineering:

- 1. Students admitted with an appropriate Bachelor's degree shall complete 60 credit hours of academic coursework in partial fulfillment of the Ph.D. degree requirements.
 - 1a. 36 credit hours CNSE coursework at the 500 level or higher with the following provisions:
 - 1.a.i. Completion of the 12 credit hours "Foundations of Nanotechnology" course sequence.
 - 1.a.ii. Completion of at least 9 credit hours of 600 or higher level coursework as advised relevant to a CNSE Nanoscale Engineering Track.
 - 1b. 9 credit hours of seminar/external courses.
 - 1c. 15 credit hours of Ph.D. dissertation research.
- 2. Students admitted with an appropriate Masters of Science degree shall complete 36 credit hours of academic coursework in partial fulfillment of the Ph.D. degree requirements.
 - 2.a. 15 credit hours CNSE coursework at the 500 level or higher with the following provisions:
 - 2.a.i. Completion of "Foundations of Nanotechnology" course sequence for which the student did not receive course equivalency upon matriculation into the Nanoscale Science Ph.D. program.
 - 2.a.ii. Completion of at least 6 credits in the student's specific Nanoscale Engineering Track.
 - 2.b. 6 credit hours of seminar/external courses.
 - 2.c. 15 credit hours of Ph.D. dissertation research.

3. ***Preliminary Written Examination for Formal Admission to the Nanoscale Engineering Ph.D. program: Admission to the Nanoscale Engineering Ph.D. program requires successful completion of a preliminary written examination covering fundamental topics in Nanoscale Science. The exam will be offered yearly and must be passed within two attempts to maintain academic standing in the Nanoscale Engineering Ph.D. program.***
4. ***Preliminary Oral Examination for completion of the Nanoscale Engineering Ph.D. degree: Normally, within 2 semesters of passing the preliminary written examination, students in the Nanoscale Engineering Ph.D. program must take and pass a preliminary oral examination relevant to a Nanoscale Engineering Track. Successful completion of the preliminary oral examination is determined by a five-member oral examination committee. This committee consists of at least three members of the CNSE faculty (including the student's advisor who serves as chair) and at least one outside member (University at Albany faculty outside CNSE, or CNSE research partner). Upon passing this examination the student advances to candidacy for the Nanoscale Engineering Ph.D.***
5. ***Submission and successful defense of a formal Ph.D. Dissertation: unchanged from existing Ph.D. requirement.***
6. ***Ph.D. Publication Requirement: unchanged from existing Ph.D. requirement.***

4) **Description of new courses:**

Foundations of Nanotechnology Sequence:

Nanotechnology is highly interdisciplinary, building upon core competencies from many traditional disciplines, including materials science, chemistry, physics, biology and electrical engineering. Because of this fact, and because the undergraduate backgrounds of CNSE students are equally diverse, a “one size fits all” approach to course content and design is neither practical nor desirable. Equally, it is not feasible to require students to take full-semester courses in other academic units on campus in order to be exposed to the fraction of material that is salient to their needs.

To address these issues, a sequence of modular core courses “Foundations of Nanotechnology” has been designed to provide students with the particular core competencies they did not acquire in their respective undergraduate programs, as well as to prepare them for their more specialized advanced coursework and individual research in the various CNSE Nanoscale Science and Nanoscale Engineering Tracks.

The Foundations of Nanotechnology sequence consists of four courses (Foundations of Nanotechnology I – IV), with two to be offered in the Fall semester and two in the Spring semester. Each course consists of coordinated modules specifically sequenced to provide the fundamental academic acumen and core competencies necessary for students entering the fields of Nanoscale Science and Engineering. A Ph.D. student must complete 12 modules to satisfy the Foundations of Nanotechnology course sequence requirement [see Section 3]. Critical aspects of the “Foundations” sequence are as follows:

- a) Each course (Foundations of Nanotechnology I – IV) will consist of five “modules” with each module designed to address a core competency for CNSE graduate study. Each module would be typically allocated 15 lecture hours in the semester. A list of the 20 modules is shown below. Bulletin-compatible descriptions and corresponding course numbers provided in Appendix B.
- b) Students must successfully complete an average of three modules per course so by the end of the Foundations sequence a Ph.D. student will have earned 12 credits of coursework toward his/their degree requirements.
- c) Individual modules will be taught on a rotating basis by CNSE faculty members.

Foundations of Nanotechnology: Module titles (see Appendix B for descriptions)

Nanoscale Analytic Techniques	Noncrystalline and Soft Materials
Crystallography and Diffraction	Optical/Photonic Properties
Deposition Techniques for Ultra-Thin Films	Particle – Solid Interactions
Nanoscale Device Principles	Phase Equilibria for Nanoscale Systems
Nanoscale Electronic and Magnetic Properties	Practical Modeling
Introduction to NEMS/MEMS	Practical Solid State Quantum Theory
Nanoscale Kinetics and Transport	Solid State Quantum Theory IA
Mathematical Methods in Research	Solid State Quantum Theory IB
Nanoscale Mechanics of Materials	Science of Nanoscale Laboratory Techniques
Molecular Materials	Nanoscale Surfaces and Interfaces

New 600-level Courses: (for full course bulletin entry see Appendix C)

CNSE 603 Nanoscale Materials Processing (3 Cr)

CNSE 604 Plasma Processing of Materials (3 Cr)

CNSE 607 FabLab (3 Cr)

CNSE 611 Introduction to Optics (3 Cr)

CNSE 612 Optical Processes in Solids (3 Cr)

CNSE 613 Practical Optoelectronics: Design, Fabrication, and System Integration (3 Cr)

CNSE 640--NanoTechnology and Photovoltaics (3 Cr)

CNSE 642--Advanced Fuel Cells (3 Cr)

CNSE 643--Power Electronics (3 Cr)

CNSE 651 Fundamentals of Lithography I (3 Cr)

CNSE 652 Fundamentals of Lithography II (3 Cr)

CNSE 653 Advanced Optics (3 Cr)

CNSE 654 Charged Particle Optics (3 Cr)

CNSE 655 Resist Chemistry and Processing (3 Cr)

CNSE 656 Alternative and Experimental Lithographies (3 Cr)

CNSE 660 Semiconductor Metrology and Defect Analysis (3 Cr)

CNSE 673 X-ray Scattering Techniques and Crystallography (3 Cr)

CNSE 674 Focused Ion Beam Technology (3 Cr)

5) New faculty:

No new faculty will be needed for the proposed revisions.

6) Additional costs:

No additional costs for the proposed revisions are anticipated.

7) Effective date:

The proposed revisions will take effect in the Fall 2006 academic semester.

Appendix A

Proposed Nanoscale Science and Nanoscale Engineering Track Descriptions

Nanoscale Science Tracks for M.S. and Ph. D. Degree Programs

Molecular Materials and Architectures: Fundamental material properties of molecular dots, wires, and crystals, quantum confinement and ballistic transport based device structures, and the integration of molecular/electronic materials in nanodevice geometries. Advanced theoretical and computer simulation treatments of nanoscale optical, electronic, elastic, and thermodynamic properties.

Optoelectronic Materials and Architectures: Compound semiconductor material properties and fundamentals of compound semiconductor ultra-thin-film growth for optical and optoelectronic applications. Quantum confinement-based optical and optoelectronic properties. Optical and optoelectronic device architectures using single and compound semiconductors.

Spintronic Materials and Architectures: Compound semiconductor material properties and fundamentals of compound semiconductor thin-film growth for spintronic applications. Magnetic and Nanomagnetic device architectures using single and compound semiconductors.

Ultra-Thin Film Single and Multilayered Nanomaterial Structures: Self-assembly, deposition, modification, and integration of single and multilayered thin film materials. Fundamental functionality relationships between nanoscale structures and dimensions and resulting film properties.

Nanoscale Materials Characterization, Analysis, and Metrology: Advanced nanoscale photon, ion, and electron based microscopic and spectroscopic analytical techniques and process metrologies for atomic and molecular-level material properties of ultra-thin films, nanomaterials and nanoscale devices and systems.

Nanomaterials for Nanotechnology: The science of design, deposition, and integration of atomic and molecular-level nanoengineered materials for nanotechnology-based applications.

Economic Impacts of Nanoscale Science and Nanotechnology: In-depth technical analysis of educational, workforce, and economic impacts of emerging nanoscale systems and architectures. Theoretical modeling and simulation studies of the technical impact of emerging nanoscale science concepts and disruptive nanotechnologies.

Nanoscale Engineering Tracks for M.S. and Ph. D. Degree Programs

Nanoelectronics Engineering and Technology: Design, Processing, fabrication, testing, and integration of nanoelectronic structures and devices for incorporation in emerging gigascale and terascale integrated circuit systems and architectures. Development of integrated process modules for novel nanoelectronics materials.

Optoelectronics and Photonics Nanoengineering: Design, fabrication, testing, and integration of integrated optoelectronic and photonic device structures using compound semiconductors. Testing and hybridization of optoelectronic/photonic devices in system-on-a-chip (SOC) and nano-electro-mechanical system (NEMS) architectures.

Spintronics Nanoengineering: Design, fabrication, testing, and integration of spintronic device structures. Testing and hybridization of spintronic devices, including incorporation in system-on-a-chip (SOC) and nano-electro-mechanical system (NEMS) architectures.

NanoSystem Engineering and Technology: Design, fabrication, packaging, and testing of nano/micro-electrical and nano/micro-opto-electrical mechanical components and nano/micro-fluidic components for incorporation in SOC architectures and systems.

NanoEngineering in Energy & Environmental Technologies: Development of nanotechnology engineering concepts for new and emerging applications in energy and environmental areas including fuel cells, solar cells, superconductors, sensors, power electronics, and supercapacitors.

Nanolithography Engineering and Technology: Design, development and engineering of nanolithography systems, components, and processes. Development and engineering of materials and metrologies for nanolithography.

Nanobiology Engineering and Technology: Design, development and engineering of nanobiological systems, components, and processes. Development and engineering of biomaterials and nano-bio-systems for SOC, nanomedicine, and health applications.

Appendix B

Module Descriptions: Foundations of Nanotechnology I - IV

Foundations of Nanotechnology Descriptions

CNSE 501: Foundations of Nanotechnology I (1-5 Cr)

Crystallography and Diffraction

Fundamental descriptions of crystalline materials structure and determination.

Phase Equilibria for Nanoscale Systems

First, second, and third laws of thermodynamics as applied to nanoscale systems; activity and the equilibrium constant; solutions; phase relations (including the phase rule); heterogeneous equilibria; free-energy-composition diagrams and their relation to phase transitions; phase diagrams.

Nanoscale Kinetics and Transport

Discussion of time-dependent mass transport in nanomaterials system through a formal treatment of diffusion theory.

Practical Solid State Quantum Theory

Practical descriptions of how physical properties and behaviors of materials become dominated by quantum effects as length scales approach atomic dimensions.

Nanoscale Mechanics of Materials

Introduction to atomic and continuum scale mechanics appropriate to nanoscale systems and assemblies, including the role of defects.

CNSE 502: Foundations of Nanotechnology II (1-5 Cr)

Mathematical Methods in Research

Introduction to the critical mathematical tools needed for research and education in nanotechnology.

Practical Modeling

Principles of modeling structures and processes at the nanometer scale, including meshing techniques, finite element analysis, and molecular dynamics.

Solid State Quantum Theory IA

Introduction to the quantum theory of nanoscale material systems and devices.

Molecular Materials

Structure, chemistry, thermodynamics and physical properties of long chain molecules and molecular structures, including polymers, electronic polymers, proteins, carbon nanotubes and fullerenes.

Science of Nanoscale Laboratory Techniques

Overview of the scientific basis of key technologies in experimental nanotechnology research, including laboratory safety.

CNSE 503: Foundations of Nanotechnology III (1-5 Cr)

Particle – Solid Interactions

Interaction of high energy photons, electrons, and ions with matter in the context of atomic scale characterization.

Nanoscale Analytic Techniques

Physical basis of the major analytical methods used for nanoscale materials analysis.

Nanoscale Electronic and Magnetic Properties

Description and atomic scale origins of the electronic and magnetic properties of matter.

Optical/Photonic Properties

The interactions between electromagnetic waves and matter (molecules, thin films, and bulk materials) is treated with particular attention to the increasing role of quantum effects as length scales approach atomic dimensions.

Solid State Quantum Theory IB

Quantum origins of physical properties in nanometer scale systems.

CNSE 504: Foundations of Nanotechnology IV (1-5 Cr)

Deposition Techniques for Ultra-Thin Films

Overview of important deposition methods used in nanomaterials synthesis.

Nanoscale Device Principles

The physical principles underlying the design and operation of modern electronic and optoelectronic devices.

Noncrystalline and Soft Materials

Introduction of the amorphous state including the structure of liquids and glassy solids. Introduction to soft materials including biological films, membranes and membrane polymers, liquid crystals and colloids.

Introduction to NEMS/MEMS

Design fundamentals of nanometer scale electro-mechanical systems

Nanoscale Surfaces and Interfaces

Introduction to surface structure, properties, thermodynamics and analysis and their role in nanotechnology.

Appendix C

Course Descriptions for New Courses for Graduate Study in Nanoscale Science and Nanoscale Engineering

CNSE 603 Processing of Nanoscale Materials (3)

Fundamentals of thin film and nanostructured materials. Kinetics, heterogeneous reactions, reaction pathways, nucleation. Plasma-enhanced techniques, plasma promoted nucleation. Atomic layer deposition fundamentals. Half-reactions, adsorption kinetics, by-product volatilization. Material characterization techniques. Safety and hardware considerations. Prerequisites: Foundations sequence, permission of instructor; offered annually.

CNSE 604 Plasma Processing of Materials (3)

Fundamental physical aspects of processing plasmas. The chemistry of plasmas. Hardware considerations in plasma processing. Specific plasma processing applications: Surface preparation and cleaning, reactive ion etching, sputtering, PECVD, and PEALD. Prerequisites: Foundations sequence, permission of instructor; offered annually.

CNSE 607 FabLab (3)

Real world teaming-based laboratory course. Students form teams to design, build, and test an actual device that operates based on the physical principles of nanotechnology in the CNSE/ANT facilities. Students will have at least one Industry/Research partner and one CNSE faculty as instructors. Prerequisites: Foundations sequence, permission of instructor; offered annually.

CNSE 611 Introduction to Optics (3)

Basic optics. Introduction to Fourier Optics, Statistical Optics, Aberration Theory. Prerequisites: Foundations sequence, permission of instructor; offered annually.

CNSE 612 Optical Processes in Solids (3)

Topics include modeling of dielectronic functions, optical absorption, energy transfer and recombination processes, elementary excitations, electro-optic and magneto-optic effects, selection rules of optical transitions, waveguides, and photonic crystals. Prerequisites: Foundations sequence, permission of instructor; offered annually.

CNSE 613 Practical Optoelectronics : Design, Fabrication and System Integration (3)

Topics include optoelectronic components design and fabrication, monolithic and hybrid integration between photonics and electronic components and associated challenges. Prerequisites: Foundations sequence, permission of instructor; offered annually.

CNSE 640 NanoTechnology and Photovoltaics (3)

Topics focus on the application of nanoengineered materials and structures to photovoltaic technologies and include impact on performance and operation. Prerequisites: Foundations sequence, permission of instructor; offered annually.

CNSE 642 Advanced Fuel Cells (3)

Topics focus on application of nanomaterials integration in and nanoengineering of emerging fuel cell geometries and concepts. Prerequisites: Foundations sequence, permission of instructor; offered annually.

CNSE 643 Power Electronics (3)

Topics focus on emerging concepts in device design and nanomaterials integration in power electronic system architectures. Prerequisites: Foundations sequence, permission of instructor; offered annually.

CNSE 651 Fundamentals of Lithography I (3)

Fundamental concepts and practices in lithographic processing. Topics include resist fundamentals, track systems, and scanner technology - based on classic text by Levinson. Prerequisites: Foundations sequence, permission of instructor; offered annually.

CNSE 652 Fundamentals of Lithography II (3)

Design data creation and manipulation. Mask making. Metrology and inspection for lithography. Prerequisites: Foundations sequence, permission of instructor; offered annually.

CNSE 653 Advanced Optics (3)

Fourier Optics. Statistical Optics. Aberration Theory. Prerequisites: Foundations sequence, permission of instructor; offered annually.

CNSE 654 Charged Particle Optics (3)

Fundamentals of charged particle optics including conventional and immersion lens approaches to focusing. Aberration theory and source technology. Prerequisites: Foundations sequence, permission of instructor; offered annually.

CNSE 655 Resist Chemistry and Processing (3)

Fundamentals of advanced resist chemistries and processing. Includes survey of negative and positive resists and application of chemically amplified resists. Prerequisites: Foundations sequence, permission of instructor; offered annually.

CNSE 656 Alternative and Experimental Lithographies (3)

Survey of alternative projection lithography, soft lithography, and direct write lithography for nanoscale patterning. Prerequisites: Foundations sequence, permission of instructor; offered annually.

CNSE 660 Semiconductor Metrology and Defect Analysis (3 Cr)

A detailed overview of current characterization methods critical to transistor fabrication, on-chip interconnection, lithography, defect detection and characterization, and process yield analysis. This course would cover the myriad techniques in use in or near semiconductor fabrication facilities that are critical to achieving acceptable process yields. This course would look at how metrology tools of the type described in SNN 661 would be actually used to solve real world manufacturing problems. Emphasis would be placed

on how to determine whether fabrication processes are correctly working and when they are not and how to do root cause analysis. Therefore the course would include descriptions of key fabrication processes encountered in real fabrication facilities. Prerequisites: Foundations sequence, permission of instructor; offered annually.

CNSE 673: X-ray Scattering Techniques and Crystallography (3)

Application of advanced x-ray scattering and diffraction techniques for the investigation of nanomaterials, nanodevice structures, and nanoscale modulated systems. Prerequisites: Foundations sequence, permission of instructor; offered annually.

CNSE 674: Focused Ion Beam Technology (3)

In-depth review of current focused ion beam technologies as developed for 3D tomographic imaging, defect review, circuit repair, and TEM sample preparation. Prerequisites: Foundations sequence, permission of instructor; offered annually.