LSC Use Only No:	LSC Action-Date:	UWUCC USE Only No.	UWUCC Action-Date:	Senate Action Date:
		03-50	Appr 4/13/04	Appr 4/27/04

Curriculum Proposal Cover Sheet - University-Wide Undergraduate Curriculum Committee

Contact Person	Email Address
Dr. Devki N. Talwar	talwar@iup.edu
Proposing Department/Unit	Phone
Physics/NSM	7-2190

Check all appropriate lines and complete information as requested. Use a separate cover sheet for each course proposal and for each program proposal.

1. Course Proposals (check all that apply)

_____New Course _____Course Prefix Change _____Course Deletion

_____Course Revision _____Course Number and/or Title Change _____Catalog Description Change

Current Course prefix, number and full title | *Proposed course prefix, number and full title, if changing*

2. Additional Course Designations: check if appropriate

_____ This course is also proposed as a Liberal Studies Course.

_____ This course is also proposed as an Honors College Course.

_______ Other: (e.g., Women's Studies, Pan-African)

3. Program Proposals

_____New Degree Program

_____New Minor Program

______Catalog Description Change

______Program Title Change

X_____New Track

_____Program Revision

_____Other

Current program name | *Proposed program name, if changing*

4. Approvals		Date
Department Curriculum Committee Chair(s)	Kenneth Hershman	3/22/04
Department Chair(s)	Kenneth Hershman	3/22/04
College Curriculum Committee Chair	[signature]	4/8/04
College Dean	John D. Eck	4/8/04
Director of Liberal Studies *		
Director of Honors College *		
Provost *		
Additional signatures as appropriate: (include title)		
UWUCC Co-Chairs	Gail S Sechrist	4-13-04

* where applicable

RECEIVED
APR - 8 2004
LIBERAL STUDIES

Part II. Description of Curriculum Change

1. **Complete Catalog Description For New Track. This includes both the description about track and the list of courses and credits for the new track.**

Catalog description

The Bachelor of Science Degree in Applied Physics with Nanofabrication Manufacturing Technology (NMT) track will help IUP students to take one semester of hands-on experience in the high-tech field of semiconductor device manufacturing at the state-of-the-art facility at Penn State - University Park Campus. Nanofabrication industries using this technology are rapidly growing from biomedical applications to microelectronics. Graduates of the Applied Physics/NMT track may enter careers in industry and education.

The students enrolled in Applied Physics/NMT track will spend one semester (16 weeks) (18 cr CAPSTONE) in their Junior/Senior year at Penn State (in the Fall, Spring or Summer (12 weeks)) for hands-on experience in high-tech semiconductor device manufacturing field. Students must earn a GPA of at least 3.0 in the required Science and Mathematics courses to be considered for admission into the CAPSTONE semester at Penn State.

List of courses and credits for the Bachelor of Science – Applied Physics/Nanomanufacturing Technology (NMT) Track

Liberal Studies: As outlined in Liberal Studies section with the following specifications — **50 cr**

Mathematics: MATH 123
Natural Science: CHEM 111-112
Liberal Studies Electives: 4 cr, MATH 124,
No courses with PHYS prefix

Major: — **28 cr**
Required Courses:

PHYS 131	Physics I-C Lecture	3 cr
PHYS 132	Physics II-C Lecture	3 cr
PHYS 141	Physics I-C Lab	1 cr
PHYS 142	Physics II-C Lab	1 cr

PHYS 222	Mechanics I	2 cr
PHYS 231	Electronics	4 cr
PHYS 242	Optics	3 cr
PHYS 322	Electricity and Magnetism I	2 cr
PHYS 331	Modern Physics	3 cr
PHYS 352	Applied Physics Laboratory	3 cr
PHYS 355	Computer Interfacing	3 cr

Controlled Electives: **24 cr**

Nanomanufacturing Technology (NMT) Track (18 cr PSU CAPSTONE)

NMTT 311	Materials, Safety and Equipment Overview for Nanofabrication	3 cr
NMTT 312	Basic Nanofabrication Process	3 cr
NMTT 313	Thin Films in Nanofabrication	3 cr
NMTT 314	Advanced Lithography and Dielectrics for Nanofabrication	3 cr
NMTT 315	Materials Modification in Nanofabrication	3 cr
NMTT 316	Characterization, Packaging, and Testing of Nanofabricated Structures	3 cr
PHYS 475	Physics of Semiconductor Devices I	3 cr
PHYS 476	Physics of Semiconductor Devices II	3 cr

Other Requirements: **9-15 cr**

COSC 110	Problem Solving and Structured Programming	3 cr
COSC 250	Introduction to Numerical Methods	3 cr
MATH 241	Differential Equations	3 cr
Foreign Language Intermediate Level [a)]		0-6 cr

Free Electives: **3-9 cr**

Total Degree Requirements: **120 cr**

[a)] Intermediate-level Foreign Language may be included in Liberal studies electives.

2. Detailed Description For The Track

Rationale/Justification

The program leading to the Bachelor of Science – Applied Physics/Nanomanufacturing Technology (NMT) Track in the College of Natural Sciences proposes a new academic track with emphasis in the high-tech semiconductor device manufacturing field. This will provide knowledge base necessary for the manufacture of any micro- and nano-scale product. The goal is to prepare our Applied Physics undergraduate students for a career in industry or academia using nanotechnology. The student will derive this valuable knowledge base from a program composed of safety training, lectures, software based training, fabrication experiments, tool training, processing training, product cost evaluation, independent research, and process integration projects. To facilitate the process integration goal, the student will be required to work on a micro- or nano-scale structure at the end of the semester as a group project.

The Physics of Semiconductor has played a major role in the development of modern micro (micro means a millionth 10^{-6}) technology, especially microelectronics, and solid state devices. Since the dimensions of new microelectronic components, e.g., computer chips are reaching to a nanometer range (nano means a billionth 10^{-9}), the research and development in semiconductor physics has been steadily moving from micro-technology to nanotechnology. Nanofabrication is the technology that grew out of making semiconductor chips. Everybody wanted faster computers and faster access to the Internet, which resulted in transistors getting smaller. Things have gotten so tiny now that this technology has become "machining at the atomic level" and it has spread from being used to make chips to being used to make a variety of technological innovations, including, for example, artificial organs, tiny valves, and flat, picture-like televisions. An understanding of the semiconductor physics involved in this new technology would be advantageous to every student majoring in Natural Sciences (Physics, Chemistry, Biology and Computer Science) and/or Engineering.

The current widespread interest in nanotechnology dates back to the years 1996 to 1998 when a panel under the auspices of the World Technology Evaluation Center (WTEC) funded by the National Science Foundation (NSF) and other federal agencies undertook a world-wide study of research and development in the area of nanotechnology innovation. The WTEC study concluded that nanotechnology has enormous potential to contribute to significant advances over a wide and diverse range of technological areas ranging from producing stronger and lighter materials to shortening the delivery time of nano-structured pharmaceuticals to the body's circulatory system, increasing the storage capacity of magnetic tapes, and providing faster switches for computers. Recommendations made by WTEC and subsequent panels have led to the appropriation of very large levels of funding. This resulted in the establishments of five 'National Nanofabrication User Networks' (NNUN) all over the country with a funding of more than $100 million dollars from the NSF. One of such networks is at the Research Park of Penn State (see: www.nnun.org).

The 23 million dollar Penn State Nanofabrication Facility is meant for the sharing of a Pennsylvania resource by educational institutions across the Commonwealth. The access of this significant resource has given opportunities to students across the state - from the SSHE universities to the community colleges - to get 18 credits of CAPSTONE experience in nanofabrication manufacturing technology (NMT). This program will be extremely valuable for our students to earn BS degree (Applied Physics/NMT track) by taking appropriate courses (described in 1) from IUP and taking one-semester (18 cr) of capstone, hands-on experience in their junior/senior year from Penn State's Nanofabrication Facility.

What is the outlook for industries using nanofabrication?

Every year some industries spurt ahead and some slow down. That is the way the world economy is. However, the ones that do more spurting ahead are the high-tech industries like optoelectronics (fiber-optic communications for the Internet), displays (flat TVs, computer screens, etc.), sensors (pollution, food bacteria detection, etc.), pharmaceuticals (DNA immobilization, "lab-on-a-chip"), and microelectronics. These industries use nanofabrication technology now and will use nanofabrication even more in the future.

What are the opportunities for a graduate of this program?

The spectrum of industries using nanofabrication technology is broad - from pharmaceuticals to opto-electronics and microelectronics. A person with a nanofabrication technology skill can work in any of these industries, all of which continue to grow. The Federal Government, in stressing the unprecedented spread of nanotechnology, has stated that it "...is likely to change the way almost everything - from vaccines to computers to automobile tires to objects not yet imaginable - is designed and made."

The industries using nanotechnology are growing from biomedical applications to microelectronics. As the worldwide nanofabrication industries continue to grow, graduates of the NMT partnership program will become an even more valuable resource. As the international use of nanofabrication manufacturing (i.e., semiconductor manufacturing-based) technologies increases across high-tech industries, individuals with this training will have an ever-growing list of companies in a variety of fields to choose from in selecting job opportunities.

- Micro- and nano- electronics
- Information Storage
- Optoelectronics
- Bio-Medical
- Chemical

Part III. Implementation

1. *How will the proposed new track affect students already in the existing program?*

The essence of the Applied Physics/NMT track is to help students in their Junior/Senior year to gain valuable experience (18 cr. CAPSTONE 16 weeks (Fall or Spring) or 12 weeks (Summer)) in nanofabrication manufacturing technology at the Penn State' Nanofabrication Facility while enrolled for the BS degree in Applied Physics at Indiana University of Pennsylvania. Students taking the CAPSTONE experience at Penn State will pay tuition for the 18 credits at IUP at the prevailing rate while Penn State will provide, through agreement with the State of Pennsylvania, the necessary boarding and lodging. Other students in the IUP physics program will not be affected at all.

2. *Are faculty resources adequate? If you are not requesting or have not been authorized to hire additional faculty, demonstrate how these courses will fit into the schedule(s) of current faculty. What will be taught less frequently or in fewer sections to make this possible?*

Since CAPSTONE experience in nanofabrication manufacturing technology will take place at the Penn State' Nanofabrication Facility, no new faculty at IUP will be needed to offer this new track and no change in other courses or programs in the physics department is foreseen.

3. *Are other resources adequate? (Space, equipment, supplies, travel funds)*

(a) No additional space is necessary to offer this new track
(b) No additional supplies are necessary for this new track
(c) No additional equipment is needed for this new track
(d) Available library materials are adequate for this new track.
(e) No travel funds are needed.

4. *Do you expect an increase or decrease in the number of students as a result of these revisions? If so, how will the department adjust?*

The number of students in this track will not significantly alter the total number of students in the Applied Physics Program.

5. *Intended implementation date (semester and year)*

The new track is expected to start as soon as it is approved. Intended implementation date is Fall 2004. Students in the Applied Physics Program with NMT track will be advised in a manner consistent with university procedures for phasing in of the 120 curricula.

Part IV. Periodic Assessment

Departments are responsible for an out-going review of curriculum. Include information about the Department's plan for program evaluation

1. *Describe the evaluation plan. Include evaluation criteria. Specify how student input will be incorporated into the evaluation process*

   To ensure that the proposed BS Applied Physics/NMT track is meeting the IUP standards of education in providing a high quality program to our undergraduates, this program will be evaluated every year.

   Student evaluations, using standard forms, will be administered with every offering of the courses at IUP in the BS in Applied Physics/NMT track.

   The students input will be incorporated by surveying them (after two years of graduation) and asking questions such as: (i) How has the Applied Physics/NMT program at IUP prepared them for their future work? (ii) How has their general perception of this world changed as a result of their Applied Physics/NMT studies at IUP? (iii) What skills/experience they feel they did not gain at IUP for their future academic/job related works? (iv) Why in their opinion, they were unable to acquire these skills/experience?

2. *Specify the frequency of the evaluations.*

   To ensure that the Bachelor of Science – Applied Physics/NMT program is current with the most recent advances in education and training, the program of courses will be evaluated continuously both by the IUP Physics and Penn State Nanofabrication faculty.

Part V. Letters of Support

A letter of support has been requested from Terry Kuzma, Penn State NMT program coordinator.

Part VI. Course Proposals

There are six new course proposals for the Bachelor of Science in Applied Physics at IUP with Nanomanufacturing technology (NMT) track. Each of these courses (already approved by the Penn State NMT program) with lectures and lab (using 23 Million Dollar Clean Room) components will be taught by the faculty members at the Penn State Nanofabrication Facility. The six courses of the NMT capstone experience (NMTT 311-316) presented here will be taught sequentially in three phases. The first phase covers NMTT 311 and NMTT 312, followed by NMTT 313/314, and then NMTT 315/316. Lab work and training will coincide with the lecture material. Lectures are generally presented for 3 hours for 4 days/week and lab sessions for 3 hours for 3 or 4 days/week in the fall and spring 16 week semester. Because of the equipment availability, labs will occasionally be required on Fridays. During summers, lectures and labs are held 5 days per week due to the shorter 12 week session.

1. NMTT 311 Materials, Safety and Equipment Overview for Nanofabrication

I. Catalog Description

NMTT 311 Materials, Safety and Equipment Overview for Nanofabrication 3c-2l-3cr
Corequisite: NMTT 312

Focuses on cleanroom protocol and provides an overview of the materials, safety and equipment issues encountered in the practice of "top down" and "bottom up" nanofabrication.

II. Course Objectives

Students will be able to

A. Identify the basic nanofabrication processing and characterization equipment including: Reactive Ion Etching (RIE), Plasma Enhanced Chemical Vapor Deposition (PECVD), Low Pressure Chemical Vapor Deposition (LPCVD), Furnaces, Rapid Thermal Annealer (RTA), Evaporator, Sputtering System, Ellipsometer, Probe Tools, Nanospec, Curve Tracer, Optical Microscope, Embossing, Optical, and E-beam Lithography equipment, Profilometer, Wet Bench, Dryers, sonicator tools.
B. Describe the uses and applications of the basic nanofabrication processing and characterization equipment and understand the health, environmental and safety issues associated with each.
C. Identify hazards associated with nanofabrication.
D. Identify materials used in nanofabrication manufacturing:
Dielectrics, Semiconductors, Dopants, Metals, Process Chemicals, Plastics, Biological molecules and systems.
E. Associate the material handling issues with each identified nanofabrication material.
F. Explain basic chemical properties of materials in relation to health, safety and environmental issues.
G. Discuss specific issues concerning biological materials.
H. Summarize basic cleanroom operation and protocol:

Students approximately occupy the Nanofab class 10 cleanroom for 2 hours a week as reinforcement of protocol.

I. Demonstrate an understanding of basic cleanroom operation and protocol.

III. Course Outline

Throughout the semester student will learn cleanroom protocol, safety, and environmental and health issues in equipment operation and materials handling. The main topics to be covered include: cleanroom operation, Occupational Safety and Health Administration (OSHA) lab standard safety training, health issues, Bio Safety Level two (BSL-2) certification, and environmental concerns. Safety issues dealing with nanofabrication equipment will also be discussed including those pertinent to tools such as furnaces, rapid thermal annealing tools, plasma based equipment, wet etch systems, heating and cooling units, stamping and embossing tools, vacuum, systems and pumps, gas delivery and detection. Specific material handling procedures covered will include corrosive and flammable gas storage, biological materials, carcinogenic materials, Deionized (DI) water, solvents, cleaners, ion implantation sources, diffusion sources, photo resists, developers, metals, dielectrics, acids, bases.

The student will become familiar with nanofabrication equipment used in material characterization and devices. The tools and equipment include evaporators, furnaces, RTA, RIE, PECVD, LPCVD, sputtering, optical microscopes, probe lithography, stamping and embossing equipment, as well as wet bench, microscope, ellipsometer, nanospec, and profilometer equipment.

They will also learn to handle the state-of-the-art processing equipment used in the Nanofabrication Facility cleanrooms and will be introduced to the principles of safe equipment operation.

IV. Evaluation method

The final grade will be determined as follows

Mid-term exam (500 points)
Quizzes (usually 3 quizzes each of 100 points = 300 points)
Lab + homework (400 points)
Independent reports and simulation (250 points)
Final presentation (300 points)
Final Exam (500 points optional)

Penn State Letter Grade Chart

Letter Grade	A	A-	B+	B	B-	C+	C	D	F
Percentage	94	90	87	84	80	76	70	60	0

V. Attendance Policy

Attendance is mandatory. Make up time is required for any absence that extends beyond two days. Failure to make up lab time results in an F grade.

2. NMTT 312 Basic Nanofabrication Processes

I. Catalog Description

NMTT 312 Basic Nanofabrication Processes **3c-2l-3cr**
Corequisite: NMTT 311

Provides a hands-on introduction to the processing sequences involved in "top down", "bottom up", and hybrid nanofabrication. Focuses on a step-by-step description of the processes integration needed to fabricate devices and structures.

II. Course objectives

Students will be able to

A. Develop an appreciation for, and an introductory grasp of, the full spectrum of micro- and nanofabrication processes.
B. Understand the approaches of 'top-down', 'bottom-up' and hybrid fabrication.
C. Understand the roles of the basic processing steps of pattern generation, deposition, etching and solution growth.
D. Understand the origins of basic manufacturing issues such as process control, yield, reproducibility, and contamination.
E. Hands on training with vacuum hardware, vacuum pumps, and associated vacuum gauges.
F. Design process flows for micro- and nano-scale systems (e.g., a microfluidic chip structure, a self-assembled array or a MOS structure).
G. Students approximately occupy the Nanofab class 10 cleanroom for 2 hours a week in device design process.
H. Learn the similarities and differences in both equipment and process flows by undertaking "hands-on" processing. Students are exposed to these processing and manufacturing issues while obtaining a hands-on introduction to basic nanofabrication processes such as lithography, wet and dry etching, self-assembly, PVD, and VPD deposition, and solution chemistry.

III. Course outline

Throughout the semester students will be engaged in hands-on introduction to the processing sequences involved in "top down", "bottom up", and hybrid nanofabrication. They will be involved in a step-by-step description of the processes integration needed to fabricate devices and structures. Students learn to appreciate processing and manufacturing concerns including process control, contamination, yield, and processing interactions. They will be involved in design process flows for micro- and nano-scale systems (e.g., a microfluidic chip structure, a self-assembled array or a MOS structure). Various strategies are discussed to prevent contamination along with contamination removal techniques. Yield will be examined as a function of contamination, process selection, and preventive measures. Students will learn the similarities and differences in both equipment and process flows by undertaking "hands-on" processing. They will be exposed to these processing and manufacturing issues while obtaining a hands-on introduction to basic nanofabrication processes such as lithography, wet and dry etching, self-assembly, PVD, and VPD deposition, and solution chemistry. The importance of environmental control (gas, liquid, vacuum) in processing is stressed.

IV. Evaluation method

The final grade will be determined as follows

Mid-term exam (500 points)
Quizzes (usually 3 quizzes each of 100 points = 300 points)
Lab + homework (400 points)
Independent reports and simulation (250 points)
Final presentation (300 points)
Final Exam (500 points optional)

Penn State Letter Grade Chart

Letter Grade	A	A-	B+	B	B-	C+	C	D	F
Percentage	94	90	87	84	80	76	70	60	0

VI. Attendance Policy

Attendance is mandatory. Make up time is required for any absence that extends beyond two days. Failure to make up lab time results in an F grade.

3. NMTT 313 Thin Films in Nanofabrication

I. Catalog Description

NMTT313 Thin Films in Nanofabrication **3c-2l-3cr**
Corequisite: NMTT 311 and NMTT 312

Provides a detailed understanding of the use and processing of thin film materials in Nanofabrication. Emphasizes the understanding and operation of the state-of-the-art deposition and etching processing equipment in the PSU Nanofabrication Facility cleanrooms.

II. Course objectives

Students will be able to learn

A. All chemical vapor deposition (CVD) processes used in nanofabrication:
   PECVD, LPCVD, Atmospheric Pressure Chemical Vapor Deposition (APCVD).
B. Understand the similarities and differences in all CVD equipment used in nanofabrication:
   LPCVD furnace, Electron Cyclotron Resonance (ECR) PECVD.
C. The operation of CVD equipment.
D. The uses of different CVD thin films in nanofabrication.
E. All physical vapor deposition (PVD) processes used in nanofabrication.
F. Understand the similarities and differences in all PVD equipment used in nanofabrication.
G. Learn to set up equipment to perform PVD.
H. Operate equipment to perform PVD:
   a. Magnetron sputtering
   b. Thermal and e-gun Evaporator
I. Learn the uses of different PVD thin films in nanofabrication.
J. Learn the similarities and differences in RIE equipment used in nanofabrication:
   Parallel plate RIE, Magnetically enhanced (ME) RIE, ECR RIE, ICP RIE, TCP RIE, and triode.
K. Understand the use of cluster tools.
L. Understand the processes in wet chemical etching techniques used in nanofabrication.
M. Learn how self-assembly works.
N. Perform a self-assembled material lab experience, and verify the structure.
O. Compare the similarities and differences in all wet chemical etching equipment used in nanofabrication.
P. Set up equipment to perform wet chemical etching.
Q. Operate equipment to perform wet chemical etching:
   Use automated wet bench baths.
R. Describe the uses of wet chemical etching techniques.
S. Explain the processes in plasma etching techniques used in nanofabrication.
T. Compare the similarities and differences in all plasma etching equipment used in nanofabrication.
U. Set up equipment to perform plasma etching.

V. Operate equipment to perform plasma etching:
Plasma therm 720 training.
W. Describe the uses of plasma etching techniques:
Plasma: liftoff, dielectric etch labs.
X. Operate a scanning electron microscope for materials characterization:
Lieca 440 SEM.
Y. Develop group problem solving and reporting skills.

III. Course outline

Throughout the semester the students will be engaged in an in-depth, hands-on exposure to deposition, including PVD, CVD, and self-assembly approaches, and to etching, including wet and dry approaches, in Nanofabrication. Students work in small teams in the hands—on component and participate in the oral and written report activities. The first part of this course covers film deposition. Deposition techniques studied include self-assembly; colloidal chemistry; atmosphere, low-pressure and plasma enhanced chemical vapor deposition; sputtering; thermal and electron beam evaporation; nebulization and spin-on. The second part of the course focuses on film removal. It covers advanced etching processes and emphasizes reactive ion etching, high-density plasma systems (ECR, MERIE, ICP, TCP, triode), ion beam etching, and wet chemical etching. This course is designed to give students experience in depositing and etching a wide variety of materials including dielectrics, semiconductors, organics, polymers, metallic materials and molecular films.

IV. Evaluation method

The final grade will be determined as follows

Mid-term exam (500 points)
Quizzes (usually 3 quizzes each of 100 points = 300 points)
Lab + homework (400 points)
Independent reports and simulation (250 points)
Final presentation (300 points)
Final Exam (500 points optional)

Penn State Letter Grade Chart

Letter Grade	A	A-	B+	B	B-	C+	C	D	F
Percentage	94	90	87	84	80	76	70	60	0

V. Attendance Policy

Attendance is mandatory. Make up time is required for any absence that extends beyond two days. Failure to make up lab time results in an F grade.

4. NMTT 314: Lithography and Patterning Techniques

I. Catalog Description

NMTT 314 Lithography and Patterning Techniques **3c-2l-3cr**
Corequisite: NMTT 311

Provides knowledge and hands-on treatment to all aspects of advanced lithography and pattern generation processes covering topics from substrate preparation to exposure using pattern transfer equipment such as stamping and embossing; ion and e-beam; and optical contact and stepper systems.

II. Course objectives

Students will be able to learn

A. The process steps necessary to produce a photolithographic pattern in positive, negative, and chemically amplified resists.
B. To describe the nature and behavior of photoactive materials such as benzocyclobutene (BCB).
C. To discuss lithographic issues in nanofabrication:
   a. Underexposure, overexposure, underdevelopment, over development.
   b. Resist removal using both wet chemistry and ashing.
D. To discuss the design and use of the e-beam tool:
   a. Explain mask layout and fabrication for photolithography using the e-beam tool.
   b. View the operation of the Lieca EBPG-5R tool in the class 10 cleanroom.
E. To describe and perform alignment and registration in photolithography.
F. Identify the equipment used in photolithography:
   a. Examine and contrast stepper based systems.
G. To operate equipment used in photolithography:
   a. Karl Suss MJB3 contact aligner, lithography station (photoresist application)
   b. Produce and examine examples of underexposure, overexposure, underdevelopment, over development in the cleanroom.
H. To modify profiles in photoresist for liftoff applications:
   a. Liftoff lab using chlorobenzine.
I. To describe the process of embossing lithography with knowledge of application and limitations.
J. To use embosser for pattern transfer.
K. To describe the process of stamp lithography with knowledge of application and limitations.
L. To use stamp pattern transfer.
M. To describe the process of probe lithography and systems with knowledge of application and limitations.
N. To use probe lithography for pattern transfer.

III. Course outline

Patterning materials on the nanoscale is a challenging aspect of nanofabrication. Tool and technique selection is key to creating products in the competitive modern workplace. This course addresses these issues and is a detailed study and use of state-of-the-art lithography equipment in the Nanofabrication Facility cleanrooms.

This course is a hands-on treatment of all aspects of advanced pattern transfer and pattern transfer equipment including probe techniques; stamping and embossing; ion and e-beam; and optical contact and stepper systems. The course is divided into five major sections. The first section is an overview of all pattern generation processes covering aspects from substrate preparation to exposure tool operation. The second section concentrates on photolithography and examines such topics as mask generation, and phase shifting masks. Chemical makeup of resists will be discussed including polymers, solvents, sensitizers, and additives. The role or dyes and antireflective coatings will be discussed. In addition, critical dimension (CD) control and profile control of resists will be investigated. The third section will discuss the particle beam lithographic techniques of e-beam and ion beam lithography. The forth section covers probe pattern generation and the fifth section explores embossing lithography, stamp lithography, and self assembled lithography.

IV. Evaluation method

The final grade will be determined as follows

Mid-term exam (500 points)
Quizzes (usually 3 quizzes each of 100 points = 300 points)
Lab + homework (400 points)
Independent reports and simulation (250 points)
Final presentation (300 points)
Final Exam (500 points optional)

Penn State Letter Grade Chart

Letter Grade	A	A-	B+	B	B-	C+	C	D	F
Percentage	94	90	87	84	80	76	70	60	0

V. Attendance Policy

Attendance is mandatory. Make up time is required for any absence that extends beyond two days. Failure to make up lab time results in an F grade.

5. NMTT 315 Materials Modification in Nanofabrication

I. Catalog Description

NMTT 315 Materials Modifications in Nanofabrication 3c-2l-3cr
Corequisite: NMTT 311

Provides detailed knowledge of the processing steps used in modifying material properties in Nanofabrication including molecular functionalization, cross-linking, metal silicidation, material oxidation, material nitridation, barrier materials, alloying, stress control, annealing, and doping.

II. Course objectives

Students will be able to

A. Contrast thermally grown oxides with spin on dielectrics.
B. Hands on experience studying material morphology with the SEM:
   a. Determine the processing parameters of dielectric materials.
   b. Deposition methods, and impact on dielectric constant etch rate.
C. Explain the concept of engineering dielectric constants for different nanofabrication applications.
D. Study the family of spin on glass and spin on dopants:
   Explain the impact of dopants on material properties, such as mechanical, optical, and electrical properties.
E. Identify the processing equipment for slicing, etching, polishing:
   Describe the procedures for slicing, etching, polishing, and epitaxial growth.

This course will cover in detail the processing steps used in modifying material properties in Nanofabrication. Material modification steps to be covered will include molecular functionalization, cross-linking, metal silicidation, material oxidation, material nitridation, barrier materials, alloying, stress control, annealing, and doping. Avoiding unintentional materials modification will also be covered including such topics as use of diffusion barriers, encapsulation, electromigration, corrosion, stress effects, and adhesion. Hands-on materials modification and subsequent characterization will be undertaken.

III. Course Outline

The purpose of this course is to provide hands-on experience across the spectrum of materials modification techniques used in Nanofabrication. The emphasis of this course is the understanding and use of state-of-the-art materials-modification equipment and materials characterization tools in the Nanofabrication Facility cleanrooms.

It provides hands on experience for (i) studying the material morphology by using SEM, (ii) understanding of deposition methods, etch rates, etc. to comprehend the processing parameters of dielectric materials, (iii) provideing concept of engineering dielectric constants for different nanofabrication applications (e.g., studying the family of spin on glass and spin on dopants), (iv) explaining the impact of dopants on material properties, such as mechanical, optical, and electrical properties, (v) identifying the processing equipment for slicing, etching, polishing and epitaxial growth.

IV. Evaluation method

The final grade will be determined as follows

Mid-term exam (500 points)
Quizzes (usually 3 quizzes each of 100 points = 300 points)
Lab + homework (400 points)
Independent reports and simulation (250 points)
Final presentation (300 points)
Final Exam (500 points optional)

Penn State Letter Grade Chart									
Letter Grade	A	A-	B+	B	B-	C+	C	D	F
Percentage	94	90	87	84	80	76	70	60	0

V. Attendance Policy

Attendance is mandatory. Make up time is required for any absence that extends beyond two days. Failure to make up lab time results in an F grade.

6. NMTT 316 Characterization, Packaging, and Testing of Nanofabrication Structures

I. Catalog Description

NMTT 316 Characterization, Packaging, and Testing of Nanofabrication Structures **3c-2l-3cr**
Corequisite: NMTT 311

This course addresses the issues and examines a variety of techniques and measurements essential for testing and controlling the final device fabrication, performance and packaging.

II. Course Objectives

Student will be able to

A. Learn a variety of techniques and measurements essential for testing, characterizing and controlling the final device performance and packaging. The emphasis will be learning with and using state-of-the-art packaging equipment in the Nanofabrication Facility cleanrooms.

B. The characterization experience includes hands on use of the Atomic Force Microscope (AFM), Scanning Electron Microscope (SEM), fluorescence microscopes, and Fourier Transform Infrared Spectroscopy (FTIR).

C. The packaging section of this course will be concerned with treating fabricated structures to ensure stability against environmental forces. This will include discussion of encapsulation materials and techniques. The importance of prepackaging techniques such as deposition/etchback and chemical/mechanical polishing for final assembly will be covered also. Packaging procedures such as die separation, inspection bonding, wire bonding, filp chip bonding, sealing and final test for electronic, biological, and microfluidic devices will be studied. A review of packaging needs for biocompatibility will be given. Problems and solutions concerning the interfacing of the macro-world with micro- and nano-scale devices will be analyzed and examined in laboratory experiences.

III. Course Outline

A. Form teams of 5 students to design a process flow for a micro or nano-scale device from preparation to packaging.
B. Describe various device characterization techniques used in nanofabrication and demonstrate competence.
C. Understand the operational physics of test equipment.
D. Identify the equipment employed for packaging assembly.
E. Explain the processes and objectives of final assembly.
F. Describe the importance of nanofabricated biocompatible materials.

G. Manufacture a microfludic structure for biological applications and solve macro-world/micro-world interfacing.
H. Observe fluid flow and mixing in a micro fluidic device.
I. Describe the issues associated with packaging.
J. Identify the equipment associated with packaging.

IV. Evaluation method

The final grade will be determined as follows

Mid-term exam (500 points)
Quizzes (usually 3 quizzes each of 100 points = 300 points)
Lab + homework (400 points)
Independent reports and simulation (250 points)
Final presentation (300 points)
Final Exam (500 points optional)

Penn State Letter Grade Chart									
Letter Grade	**A**	**A-**	**B+**	**B**	**B-**	**C+**	**C**	**D**	**F**
Percentage	**94**	**90**	**87**	**84**	**80**	**76**	**70**	**60**	**0**

V. Attendance Policy

Attendance is mandatory. Make up time is required for any absence that extends beyond two days. Failure to make up lab time results in an F grade.

Master Syllabus

Nanofabrication Manufacturing Technology (NMT) Capstone Experience
(16 Week Session)

The objective of the NMT program is to develop the knowledge base necessary for the manufacture of ***any micro- and nano-scale product***. The goal is to prepare an individual for a career in industries using nanotechnology, semiconductors based industries, and their supplier industries. You will derive this valuable knowledge base from a program composed of safety training, lectures, software based training, fab experiments, tool training, processing training, product cost evaluation, independent research, and process integration projects. To facilitate the process integration goal, you will be required to work on a micro- or nano-scale structure at the end of the semester as a group project.

The six courses of the NMT capstone experience (NMTT 311-316) are presented sequentially in three phases. The first phase covers 311 and 312, followed by 313/314, and then 315/316. Lab work and training will coincide with the lecture material. Lectures generally will be presented for 3 hours for 4 days/week and lab sessions for 3 hours for 3 or 4 days/week in the fall and spring 16 week semester. Because of equipment availability, labs will occasionally be required on Fridays. During summers, lectures and labs are held 5 days per week due to the shorter 12 week session.

Required Course Materials:

Texts:

1. Semiconductor Manufacturing Technology
   by Michael Quirk and Julian Serda [Prenice-Hall : ISBN 0-13-081520-9]2.
2. Nanotechnology A gentle introduction to the next big Idea
   by Mark Ratner, Daniel Ratner [Prentice Hall : ISBN 0-13-101400-5]
3. Nanofab Safety Manual
4. Class notes in printed form
5. Notes issued during class
6. Equipment training notes
7. Lab experiment notes

Course Content:

The NMT Capstone Experience is the sum of three integrated types of exposures:
1. Safety training, equipment training and processing experience.
2. Independent study utilizing the text books, literature and general library references. Group projects.
3. Lectures and presentations

The tests and quizzes will draw from all three areas.

The *lab portion of the course* will consist of several distinct areas: Nanofab safety, protocol, and processing training, and Lubert training facility use. There will be multiple groups rotating through this process. Lab groups will be staggered to share the availability of processing tools and assure quality training. Lubert training will consist of a software based vacuum simulator, the MKS hardware vacuum trainer. All results from lab research will be formally submitted as a written report. Utilization of the facilities is dependant upon equipment breakdown, staff availability, industrial use, and probably the most unpredictable element - group progress. We will have to work together to maximize efficiency.

As an assigned research project, during the NMTT 313/314 block, groups will analyze special topics, and then teach their peers the detailed subject matter. Typical projects include, analyzing the purchase of a processing system, detailing bonding procedures for microfluidic channels, creating a mask design for an e-beam system, or creating and analyzing unique thin film profiles that are analyzed in the SEM. These reports are very detailed and historically the students have enjoyed building confidence in their craft of nanofabfication. The group research project will be presented to the class and submitted in written form. Your presentations will be critiqued and partially graded by your classmates. A detailed written report will be graded by the instructor.

During the NMTT 315/316 block, the final project will pull together your lab experience and processing knowledge. The project will also sharpen your communication skills. Successful completion of the specific project assigned to a group will provide valuable experience for tackling *any micro- or nanofabrication project.* Your group's specific project could be a microfluidics structure, a sensor, a diode, or a transistor. As a group, you will develop and undertake the process flow design using your accumulated lab experience, filling any voids with research. The project will be graded in the presentation format and as a written report. Your presentations will be critiqued and partially graded by your classmates. A detailed written report will be graded by the instructor.

Grading Procedures

NO WORK WILL BE ACCEPTED LATE. The capstone experience is based on hands-on work; consequently any tardiness and absence will decrease your grade. More than 2 absences per semester will decline your overall average grade by 3%, with each additional day worth 5%. If a student is late more than 3 times per semester, the individuals semester grade will be decreased by 2% for each additional tardiness. The student must give a written explanation for absences and tardiness. An attendance sheet is attached to the classroom door, and the missed time must be documented before re admittance to the class. Failure to document missed time will result in termination from the program.

Since this course is based on attendance and participation, dismissal from the program will occur when students do not participate in a professional manner. Once a limit of 10% of the class time is missed the students are subject to dismissal from the program. Once a limit of 7 days tardy is reached, the student is subject to failure of the semester. Students that refuse to aid in group activities and the interview process will also be failed for the semester. Once a student fails any semester, they are removed from the program, and they are ineligible to take the capstone again.

Students are required to follow the PSU Code of Student Conduct in addition to their home school conduct rules. The PSU code of Conduct addresses behavior that can warrant suspension or termination from the program. The students are required to review and follow these rules. A non-inclusive brief overview of unacceptable behavior includes; violence, threats, unsafe behavior, drug or alcohol abuse, theft, plagiarism, or sexual harassment. These policies are located in detail on the web at http://www.sa.psu.edu/ja/PoliciesRules.pdf. Students are required to sign a statement that they have read and understand the PSU Code of Student Conduct and the grading policy in this syllabus, and they will abide by these provisions.

The following general format will be used to determine grades. One quiz can be made up within 2 days. The point value will be 60% of the actual score. Semester point values may change due to number of quizzes, and if quizzes are offered in the take home format. The grading scale will follow the Penn State A, A-, B+, format. The point value from the final project and the final exam will be added to all of the grades in all 6 courses. As outlined above, grades will be reduced for absence or tardiness to help employers appraise staff value. Students are required to report attendance matters via email or voice mail, just as you would on the job. Participation is also documented daily in the lab.

Approximate Point Values						
NMTT 311/312, 313/314, and 315/316	**Midterm**	**Quizzes**	**Lab + Homework**	**Independent Reports + Simulations**	**Final Presentation**	**Final Exam (Optional)**
Possible points	500	Usually 100 points each. 300 total	400	250	300	500

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The general Penn State calendar is available at www.psu.edu/ur/calender.html. The actual NMT class schedule for a given session (spring, summer, or fall) will be available during that session and, at any time, should accurately anticipate the week of events. However, it is subject to change at short notice, and should be checked regularly. Evening exam review sessions will be held a few days before the exam.

NMT WEEKLY LECTURE AGENDA NMTT 311/312		
Week	**Major Tasks**	**Events**
1	Safety, vacuum technology, dangers in the NMT manufacturing environment Methodology Top down processing verses bottom up processing.	Ch1 (intro) pages 1-20 no Questions Ch5 (chemical in mfg) pages 91-111 Q 8,10,14,15,19,20,24,28 NNBI read 1-36 no Questions
2	Nano materials properties. Vacuum pump types and technology. Mean free path for vacuum. Evaporator block diagram. MOS as a fabricated structure;	Ch2 (char of SC) pages 21-42 Q 3,4,5,6,11,14. Ch8 (Vacuum) pages 181-197 Q 3,4,6,7,15,19,20,23. quiz1
3	Role of temperature /chemistry/ bombardment in processing. Oxidation. Growing wet/dry oxide charts. Litho overview. Intro to plasmas, and processing tool sets - COO (cost of ownership).	Ch10 (oxidation) pages 225-255 Q 1,2,5,8,13,1423,47,50.
4	Block diagrams of ion implanter, RGA,. DI water. Microcontamination. Preventing and cleaning microcontamination. Importance of load locks for throughput and contamination. Resume' review. MKS vacuum trainer.	Ch17 (ion implant) pages 475-513 Ch6 (contam. control) pages 113-146 Q 3,5,9,10,31,33,44,54,57 quiz2
5	Block diagram of the RIE, magnetron sputtering system and PECVD. All system block diagrams with TCB. Isolating the chemical and physical "knobs" on systems to control the process. BPSG / CMP. COO.	quiz3
6		Exam 1 - Week 1-5

NMT WEEKLY LECTURE AGENDA NMTT 313/314		
Week	**Major Tasks**	**Events**
6	Continue block diagrams of RIE, MERIE, PECVD, LPCVD, SPUTTER, ION IMPLANT, EVAPORATOR. Link concepts concerning thin films to hardware on process tools. Critical thinking - analyzing processing tool parameters and their effect of thin films. Night review of Midterm 1 Issue first formal group project - . Due – week 11.	Exam 1 Week 1-5 Ch16(etch) pages 435-474 Q 2,5,8,9,11,31,32,41,63 Ion implant homework issued in class.
7	Advanced Plasma technology for processing, Dry etch/DC bias/ polymers for sidewalls. Common plasma chemistry for etch. Algorithms for dry etch analysis. PT 720 – P5000 block diagrams – contrasts. High density plasma systems. Carbon/fluorine ratio effects of sidewalls and sidewall polymer formation for SiO2 etch. Silicon nitride applications and traits. Wet etch chemistry.	Quiz 4 Ch11 (deposition) pages 257-296 Q 1,2,6,7,15,17,22,23,27,40
8	Group project interim peer review. PECVD overview. Start advanced litho. Importance of graph and data presentation. In depth look at contact printing with emphasis on chemistry. Novel lithography techniques including embossing litho, stamp litho, probe litho, and self assembly lithography.	Ch13 (chemistry for litho fundamentals) pages 335-366 Q2,3,4,5,13,14,19,30,31,32,40,43,44,48 Quiz 5 NNBI read 37-61
9	Advanced lithography systems and techniques. Start lab group rotation for statistics review.	Ch14 (photo systems) pages 367 - 412 Q2,7,12,19,24,25,27,31,34,35,36,37,38, 45, 57
10	Continue advanced litho with chemistry. Ebeam + steppers. Production yield and economics. Finish Statistics review for manufacturing. Group project presentation #1.	Quiz 6
11	Exam 2	Exam 2 - Week 6-10

NMT WEEKLY LECTURE AGENDA NMTT 315/316		
Week	**Major Tasks**	**Events**
11	First group presentation. Issue Final Project. Central Dogma of biology. DNA analysis using the PCR reaction. Scaling of biological devices, and the relationship to nanomanufacturing systems and materials. Nanoscale products for biological applications. Microfluidic channel as a fabricated structure.	Issued bio questions, plus lab questions NNBI read 63-81, 107-120
12	Exam 2 review Self assembly, thiol gold interaction, alkysilanes on silicon dioxide, pen dip lithography, micro-contact printing, molecular ruler nanolithography. Nanotubes. Metalization – traits of metal and alloys for nanofabrication, Critique systems for usefulness for metal deposition. Specialized sputtering systems. CMP + BPSG revisited, Dielectric K engineering.	Quiz 7 bio and dielectrics Ch12 (metalization) pages 299-333 Q1,2,5,6,7,8,9,12,16,18,19,20,21, 27,28,34 Ch18 (CMP) pages 515-543 Q.1,2,6,13,20
13	Final Project interim peer review. Optical applications of nanofabricated materials Thanksgiving break	Quiz 8 metal Ch20 (packaging) pages 571-592 Q 2,3,8,10-13,16,18,21,22,24-26 NNBI read 121-140
14	December 1, comp day for night exam review Metrology. Packaging and product testing.	Quiz # 9 opto / packaging Ch19 (wafer test) pages 545-569

	Testing materials and devices. Atomic force microscope. FTIR. C/V. *Interconnects and copper technology*	Q 1,5,8,11,25,39
15	Exam #3 Final presentation on project processing. Issue final grades.	Exam 3 Week 11-15
16	Optional Final Exam	Comprehensive

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