PLANNING FOR THE FUTURE: DEVELOPMENT OF AN ASSOCIATE DEGREE IN NANOTECHNOLOGY MANUFACTURING TECHNOLOGY AT PENN STATE UNIVERSITY

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While not long ago nanotechnology was confined to university research laboratories, nanotechnology techniques are today becoming integrated into mainstream industries. A sharp increase is predicted in the number of industries and processes that will use different nanotechnology approaches for their products in the near future. In fact, the NSF predicts that nanotech innovations will create a $1 trillion business within the next 10 to 15 years. [1] This will create a demand for a large workforce of highly qualified and trained technicians and technologists to run the processes needed, to troubleshoot this expensive equipment and to assist in the development of products using nanotechnology approaches. At the present time, universities have approached nanotechnology from the research and development side, producing highly qualified researchers in the field. The majority of the existent educational programs, if not all, have been at the graduate level. This creates an unbalance between the current and future need of technicians trained in the nanotechnology field. The number of qualified individuals will continue to grow at a more rapid pace; demand will outgrow supply. To respond to this demand, the Commonwealth College at Penn State University has developed a unique associate degree in Nanotechnology Manufacturing Technology that was started at four campuses in the Fall 2003 semester. This program is a unique and pioneering two-year program, with two different tracks: the engineering technology option (ET) and science option (SC). Both of these options converge in a hands-on capstone semester that all of the students take at the multi-million dollar Nanofabrication Manufacturing facility at the University Park campus of Penn State. The goal of this paper is to describe this innovative program as well as to share the authors' experiences in developing a cutting-edge degree in engineering technology.

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Background

Nanotechnology is an umbrella term that covers many areas of research dealing with objects that are measured in nanometers. A nanometer (nm) is a billionth of a meter, or a millionth of a millimeter. Research is being conducted in many different areas, including biology, chemistry, physics, and most branches of engineering. The NSF predicts that nanotech innovations will create a $1 trillion business within the next 10 to 15 years. In January 2000, U.S. President Clinton requested a $227-million increase in the government's investment in nanotechnology research and development, which included a major initiative called the National Nanotechnology Initiative (NNI). The NNI includes the NSF, Department of Defense, Department of Energy, National Institute of Health, Department of Homeland Security, National Institute of Standards and Technology and NASA. This initiative nearly doubled America's 2000 budget investment in nanotechnology, bringing the total invested in nanotechnology to $497 million for the 2001 national budget and increased to $847 million in 2003. [2]

President Bush signed the 21st Century Nanotechnology Research and Development Act on December 3, 2003. The U.S. House of Representatives and the Senate both approved the nanotech legislation. The law authorizes nearly $3.7 billion over four years for research and development programs coordinated among several federal agencies. According to the bill, ten federal agencies, such as the National Science Foundation, would award grants to six nanoscience research centers established by the National Nanotechnology Initiative. It authorizes public hearings and expert advisory panels, as well as the American Nanotechnology Preparedness Center to study the emerging technology's potential societal and ethical effects.[3] About 70 percent of the new nanotechnology funding will go to university research efforts, which will help meet the demand for workers with nanoscale science and engineering skills. The initiative will also fund the projects of several governmental agencies. Much of the research will take more than 20 years to complete, but the process itself could touch off a new industrial revolution. Nanotechnology is likely to change the way almost everything, including medicine, computers and cars, are designed and constructed. This will create a demand for a large workforce of highly qualified and trained technicians and technologists to run the processes needed, to troubleshoot this expensive equipment and to assist in the development of nano products.

Penn State's involvement in Nanotechnology

The Penn State Nanofabrication Facility is a one-of-a-kind university resource in Pennsylvania. It is a state-of-the-art, fully equipped national facility (>$80million) for micro- and nanofabrication and is part of the federal government's National Nanofabrication Users Network. The Penn State Nanofabrication Facility has a professional engineering staff, Class Ten cleanrooms, and a broad spectrum of processing equipment. The Nanofabrication Facility serves the Commonwealth through the Nanofabrication Manufacturing Technology program and serves the national university and industry communities through research, development, and prototyping activities requiring micro- and nanofabrication techniques. The Mission statement of the PSU Nanofab facility is as follows:

"The Penn State Nanofab is focused on developing, sustaining, and utilizing micro- and nanofabrication in the support of user R & D activities in a wide range of areas including physics, chemistry, medicine, biology, and engineering. The Nanofab is also committed to Nanofabrication Manufacturing Technology (NMT) workforce development and education through its NMT Program and outreach activities including Nanotech Camps for students in grades 7-12 and workshops for secondary and post-secondary educators."[4]

Commonwealth College

The Commonwealth College (CWC) was created in July 1997 to serve the educational needs of local Pennsylvania communities by promoting the development of intellectual and personal excellence in a supportive and inclusive learning community. The CWC consists of 12 campuses spread out across the state and offers over 20 associate-degree programs in a variety of allied health, business, engineering technology, and science fields. The CWC also provides instruction for the first two years of most of Penn State's baccalaureate majors available for completion at University Park and other locations and it provides all course work for 13 baccalaureate degrees which may be completed entirely within the College.[5]

Degree Development

To serve the need of training highly qualified technologists with knowledge on Nanomanufacturing techniques within Penn State, the Commonwealth College, in the Summer of 2002, charged a committee with developing the appropriate degree to accomplish these goals. This committee was formed by four faculty members with backgrounds in chemistry, engineering, biology, information sciences and bioengineering. This committee developed an associate degree in Nanofabrication Manufacturing Technology (2NMT) with two different tracks:

A. The Engineering Technology Option (2NMT/ET)
B. The Nanomanufacturing Science Option (2NMT/SC)

This new degree was approved by the University Faculty Senate in Spring of 2003 and started at four different Commonwealth College locations in Fall of 2003. Three of these campuses (Fayette, Hazelton and Wilkes-Barre) offer the 2NMT/ET option while the York Campus offers the 2NMT/SC option. The locations where the degree is offered will be reconsidered after producing the first graduates. Each of these degree options will be discussed below.

Engineering Technology Option (2NMT/ET)

The 2NMT/ET Degree Option curriculum is identical to present 2EET (Electrical Engineering Technology) degree program during the first two semesters. The 2EET is well established and offered at five Commonwealth College campuses. The uniqueness of the program becomes evident in the third semester, when students take a statistics course, a chemistry course, a course entitled "Introduction to Nanofabrication Manufacturing Technology" (NMT 210W), and a one-credit quality control course (NMT 250). At most campuses, NMT 210W and EMET 350 are the only additional courses required to be added in order to deliver this degree. In the final semester the students would be required to attend classes at the NMT Facility at the University Park campus and complete successfully the six capstone NMT courses delivered there using the equipment available at the facility. This degree will prepare graduates for technical positions in

the expanding fields of nanofabrication technology or professional nanomanufacturing technology, biotechnology, and/or work in biomedical industries (bionanofabrication). The primary objective of this degree option is to provide a broad foundation of theoretical and practical knowledge in the areas of nanofabrication manufacturing, electrical and electronic circuits, digital circuits, nanofabrication manufacturing equipment, processing and testing.

For the Associate in Engineering Technology option in Nanofabrication Manufacturing Technology, 72 credits are required. The program will be submitted for accreditation to the appropriate commission of the Accreditation Board for Engineering and Technology (ABET) at each campus where the full two years of the program are offered. A typical course sequence is shown in the table below.

Associate Degree in Nanofabrication Manufacturing Technology
Engineering Technology Option

First Semester		Second Semester	
Engineering Design & Graphics	3	Technical Physics	3
Electrical Circuits I (DC circuits)	3	Electrical Circuits I I (AC Circuits)	4
Electrical Circuits Laboratory I	1	Electrical Circuits Laboratory II	1
English Composition	3	Digital Electronics	3
Technical Mathematics I	4	Digital Electronics Laboratory	1
Humanities Elective	3	Technical Mathematics II	3
Credits this Semester:	17	Humanities Elective	3
		Credits this Semester:	18

Third Semester		Fourth Semester Capstone Semester at the Nanomanufacturing Facility located at University Park	
Chemical Principles with Laboratory	4	Materials, Safety and Equipment Overview for Nanofabrication	3
Quality Control for Nanotechnology	1	Basic Nanofabrication Process	3
Speech Communication	3	Thin Films in Nanofabrication	3
Introduction to Nanotechnology	3	Advanced Lithography and Dielectrics for Nanofabrication	3
Elementary Statistics	4	Materials Modification in Nanofabrication	3
Humanities Elective	3	Characterization, Packaging, and Testing of Nanofabricated Structures	3
Credits this Semester:	18	Credits this Semester:	18

2NMT/SC Degree Option

The foundation of the 2NMT/SC Degree Option was an already established science associate degree. The proposed course NMT 210W is the only new course proposed for immediate implementation of the 2NMT/SC option. Students in the 2NMT/SC program have an opportunity to select a biology, chemistry, or engineering course; this flexibility makes the program even more attractive by allowing students to focus on areas that address their specific goals and interests. The 2NMT/SC option has also been developed to provide baccalaureate engineering students an opportunity to obtain this associate degree by taking and passing NMT 210W. As with the 2NMT/ET option, students in their final semester are required to attend classes at the NMT Facility at the University Park campus and complete successfully the six capstone NMT courses (ESci) delivered there. A typical course sequence is shown in the table below.

Associate Degree in Nanofabrication Manufacturing Technology –

Science Option

First Semester		Second Semester	
Basic Biology and Biodiversity	4	Chemical Principles I & Laboratory	4
Electrical Circuits I (DC circuits)	3	Introduction to Algorithmic	3
Electrical Circuits Laboratory I	1	Physics: Mechanics	4
English Composition	3	Humanities Elective	3
Calculus I	4	Humanities Elective	3
Humanities Elective	3		
Credits this Semester:	18	Credits this Semester:	17
Third Semester		**Fourth Semester** Capstone Semester at the Nanomanufacturing Facility located at University Park	
Chemical Principles II & Laboratory	4	Materials, Safety and Equipment Overview for Nanofabrication	3
Physics: Electricity & Magnetism	4	Basic Nanofabrication Process	3
Speech Communication	3	Thin Films in Nanofabrication	3
Introduction to Nanotechnology	3	Advanced Lithography and Dielectrics for Nanofabrication	3
Elementary Statistics	4	Materials Modification in Nanofabrication	3
Credits this Semester:	18	Characterization, Packaging, and Testing of Nanofabricated Structures	3
		Credits this Semester:	18

Capstone semester at University Park

For both the 2NMT/ET and 2NMT/SC options, students must spend one semester at the NMT facility at University Park where they will be required to take the following six courses, each one worth 3 credits:

- **Materials, Safety and Equipment Overview for Nanofabrication**

This course provides an overview of basic Nanofabrication processing equipment and material chemistry and handling procedures. The focus is on cleanroom protocol, safety, environmental and health issues in equipment operation and materials handling. Topics to be covered will include: cleanroom operation, safety, and health issues; vacuum pump systems operation, turbomolecular, cryo, diffusion, and dry mechanical pump systems); furnace operation, safety, environmental, and health issues (covering horizontal and vertical tube furnaces, and rapid thermal annealing tools); chemical vapor deposition system operation, safety, environmental, and health issues (covering gas delivery, corrosive and flammable gas storage, plumbing, regulators, and mass flow controllers); and vacuum deposition/etching system operation, safety, environmental, and health issues (covering microwave and RF power supplies, tuners, heating and cooling units, vacuum gauges, valves, and process controllers). Specific materials handling issues will include DI water, solvents, cleaners, ion implantation sources, diffusion sources, photoresists, developers, metals, dielectrics, and toxic, flammable, corrosive, and high purity gases as well as packaging materials.

- **Basic Nanofabrication Process**

This course provides an overview of basic processing steps in Nanofabrication (contact lithography, basic etching and deposition techniques). The majority of the course details a step-by-step description of the equipment and processes needed to fabricate devices and structures. Processing flow will be examined for structures such as microelectronic devices including diode, and the MOS capacitor. Students receive an in-depth introduction to basic lithography from wafer preparation to final inspection. Contamination issues in nanofabrication are discussed in detail. Students will learn the similarities and differences in

both equipment and process flows for each configuration by undertaking "hands-on" processing.

- **Thin Films in Nanofabrication**

This course covers advanced thin film deposition and etching practices in Nanofabrication. Advanced deposition techniques covered in the first part of the course include: atmosphere, low-pressure and plasma enhanced chemical vapor deposition, sputtering, thermal and electron beam evaporation. Materials studied include: dielectrics (nitride, oxide), polysilicon (doped and undoped), and metals. The second part of the course focuses on advanced etching processes and techniques emphasizing: reactive ion etching (single wafer, batch), high-density plasma systems (ECR, MERIE, ICP), ion beam etching, and wet chemical etching. Students will receive hands-on experience in depositing and etching dielectric, semiconductor, and metallic materials using state-of-the-art tools and practicing many of the steps critical to Nanofabrication of semiconductor devices including microelectronics, MEMs devices, display structures, and structures used in the biotechnology fields**.**

- **Advanced Lithography and Dielectrics for Nanofabrication**

This course covers all aspects of advanced lithography from design and mask fabrication to pattern transfer and inspection. The course is divided into three major sections. The first section describes the advanced lithographic process from substrate preparation to exposure. Most of the emphasis is on understanding the nature and behavior of photoresist materials. The second section examines systems and techniques that define patterns. This section will introduce specialized optical masks and reticles, aligners, steppers and scanners. In addition, critical dimension (CD) control and profile control of photoresists will be investigated. The last section will discuss advanced optical lithographic techniques such as phase shifting masks and illumination schemes as well as e-beam, e-ray, EUV, and ion beam lithography. A section about engineering dielectrics is also included.

- **Materials Modification in Nanofabrication**

This course will cover in detail the processing steps used in modifying material properties in Nanofabrication. Evaluate thermal budget requirements using state-of-the-art tools. An intensive study of metals used in nanotechnology aids the student in understanding the various methods of metalization such as: CVD, evaporation, and sputtering. Metal applications for interconnect technologies will be examined. Aluminum, refractory metals and cooper deposition techniques and characterization will be discussed in detail along with topics such as diffusion barriers, contact resistance, electromigration, corrosion, stress effects, and adhesion. Other modification technologies such as ion implantation, diffusion and surface preparation and treatment are integrated as well. An intensive study of dielectric properties and materials, including dielectric constant engineering, mechanical, optical, and electrical characteristics, poly, BSG, PSG, SOG, and BPSG gives the student further insight into advanced device fabrication. Material properties and basic device structures will be discussed for the optoelectronic market.

- **Characterization, Packaging, and Testing of Nanofabricated Structures**

This course examines a variety of techniques and measurements essential for controlling device fabrication and final packaging. Characterization techniques, such asmastery of surface profilometry, advanced optical microscopy, optical thin film measurements, ellipsometry, and resistivity/conductivity measurements, will be implemented using nanofabricated samples. Basic electrical measurements on device structures for yield analysis and process control will also be stressed. These will include breakdown measurements, junction testing, and C-V and I-V tests and simple transistor characterization. In addition, students will examine mechanical as well as electrical characteristics of nanostructures for biological/biomedical applications. The students will perform DNA analysis by learning and performing the polymerase chain reaction for DNA replication. They will also study and manufacture microfluidic channels for biological analysis. An extensive overview of biology will be given with emphasis on biocompatible materials. The student will also learn about the manufacturing issues involved in subjects such as interconnects, isolation, and final device assembly. The importance of planarization techniques such as deposition/etchback and chemical/mechanical polishing will

be emphasized. Lastly, packaging procedures such as die separation, inspection bonding, sealing and final test for both conventional IC's and novel MEM and biomedical devices will be examined.

These courses are unique as they combine theoretical knowledge and a strong hands-on experience in the laboratories of the facility. The faculty teaching these courses are highly experienced in this type of work thus providing the students with a unique practical experience.

Course Development

As shown in the previous course requirements, one of the main attraction of this degree is that it uses courses and knowledge currently in place at the Commonwealth College, limiting the number of new courses that needed to be developed. The two courses that needed to be developed are described below:

NMT 210 W Introduction to Nanofabrication Manufacturing Technology (3 credits)

This course provides an overview of basic Nanofabrication Manufacturing Technology for Engineering and Technology students. The course will give the students an overview of atomic physics and the use of atoms to build devices and machines. Students will study the NMT industry and learn about applications in MEMS, Bionanofab technology and nanochemical applications. Students will become familiar with the basic concepts of NMT including atoms and semiconductors, transistors and integrated circuits. The students will learn about NMT applications and become familiar with the NMT industry. This is the first in a series of courses necessary for students to succeed in the Nanofabrication industry.

NMT 250 Introduction to Nanotechnology Quality Control and Quality Assurance (1 credit)

This course provides an overview of basic Quality control and quality assurance for Nanomanufacturing Technology students. Students will obtain fundamental understanding of modern statistical quality control methods used by industry. The course will cover the concepts, principles, procedures, statistical tools, and computations used to analyze and maintain statistical control of nanofabrication manufacturing and production processes and systems. The students will become familiar with the quality control processes and

applications used in the nanotechnology industry, with special emphasis in Industry Standards.

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