

**A REGIONAL CENTER  
FOR MANUFACTURING EDUCATION IN NANOFABRICATION**

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**The Penn State Nanofabrication Facility**

On July 9, 2001, the National Science Foundation designated the Pennsylvania Nanofabrication Manufacturing Technology (NMT) Partnership as a Center for Manufacturing Education in Nanofabrication. This designation represents a major milestone in the continuing development of the Pennsylvania NMT Partnership, a unique education collaborative involving The Pennsylvania State University, Pennsylvania's 14 community colleges, the 14 comprehensive public universities of the State System of Higher Education, secondary schools, private industry, and other participants.

The Pennsylvania NMT Partnership was established in 1998 with support from the Commonwealth of Pennsylvania. The primary purpose of the NMT Partnership is to help meet an industry need for technicians skilled in nanofabrication by leveraging the Penn State Nanofabrication Facility, one of just five facilities of its type in the nation, to strengthen associate degree programs in nanofabrication at Pennsylvania community colleges. The Penn State Nanofabrication Facility was established in 1994 as part of the National Science Foundation (NSF) sponsored National Nanofabrication Users Network (NNUN). In addition to Penn State, the NNUN includes Cornell University, Howard University, Stanford University, and the University of California at Santa Barbara. Through the NNUN, the NSF supports nanofabrication "users' facilities" at each of these universities as locations where academic and industrial researchers have access to the

equipment and engineering expertise needed to perform nanotechnology research.

The Penn State Nanofabrication Facility began operating in 1994, and Penn State officials began to hear almost immediately from industrial users of the Facility about the need for associate-degree level technicians skilled in micro- and nanofabrication. Pennsylvania companies expressing these concerns represented the information storage, microelectronics, biotechnology, and opto-electronics industries, as well as nanofabrication equipment and supply vendors. In 1997, these companies proposed to Governor Tom Ridge that the Commonwealth of Pennsylvania provide funding for an educational initiative that would leverage the Penn State Nanofabrication Facility to help meet the need for nanofabrication technicians. Industry has guided every phase of the development of the NMT Partnership since its inception in 1998.

Reflecting industry priorities, the primary focus of the NMT Partnership is on meeting the need for associate degree level nanofabrication technicians. Traditionally, community and technical colleges meet the needs of industry for trained associate degree level technicians. However, while Pennsylvania's 14 community colleges specialize in associate degree level education, they possess no nanofabrication facilities or expertise. Penn State, a leading national research university, does not specialize in associate degree level education, but Penn State houses the NNUN site and possesses the expertise needed for training nanofabrication workers. Thus the NMT Partnership was born.

In 1998, the nation's first associate degree programs in nanofabrication were established at community colleges across Pennsylvania through the NMT Partnership. The key feature of the NMT Partnership that enables the community colleges to offer

these programs is a suite of six nanofabrication courses taught three times per year (fall and spring semesters and summer session) at the Penn State Nanofabrication Facility. The Penn State Nanofabrication Facility staff teaches these six courses, called the “capstone semester,” for the community colleges. Community college students pay only their regular community college tuition to attend the capstone semester. State funding makes up the difference between these tuition amounts and the much higher cost of teaching the capstone semester.

A brief summary of the content of each of the courses comprising the capstone semester is shown on Table 1. These six courses include hours per day of supervised, hands-on experience in the state-of-the-art Penn State Nanofabrication Facility with its class 10 and class 1 cleanrooms and full spectrum of processing tools. These students learn and practice all aspects of nanotechnology including dry etching, ion implantation, photo- and e-beam-lithography, physical and chemical vapor deposition, and molecular self-assembly techniques. Both “top-down” and “bottom-up” nanofabrication are covered, and it is stressed that students are establishing an educational foundation that is to be built upon as nanotechnology continues to evolve and permeate into more areas of science and industry.

The six courses comprising the nanofabrication capstone semester are listed as approved engineering courses in the Penn State course catalogue. They are also listed as approved courses in the course catalogues of each community college. Community college students register for the capstone semester courses at their community college. Each community college awards its credits for the six courses and offers them as part of

Table 1

The Six Capstone Semester Courses  
Of the Pennsylvania NMT Partnership

Penn State Course Number and Name	Summary of Course Content
ESCI 211: Materials, Safety, Health Issues, and Equipment Basic to Nanofabrication	Provides an overview of basic nanofabrication processing equipment and materials handling procedures with a focus on safety, environment, and health issues.
ESCI 212: Basic Nanofabrication Processes	Provides an overview of the equipment and processes used to fabricate devices and structures such as complementary metal oxide semiconductor (CMOS) transistors and power devices, micro-electromechanical (MEM) devices, and biomedical devices including “lab-on-a-chip” structures.
ESCI 213: Thin Film Utilization in Nanofabrication	Addresses thin film deposition and etching practices, including atmospheric, low pressure, and plasma enhanced chemical vapor deposition and sputtering, thermal evaporation, beam evaporation, physical vapor deposition, reactive ion etching, high-density plasma reactors, ion beam etching, and wet chemical etching.
ESCI 214: Lithography for Nanofabrication	Covers all aspects of lithography from mask design and fabrication to pattern transfer and inspection, This course addresses photo-resist materials, optical masks, aligners, steppers, scanners, and advanced optical lithographic techniques.
ESCI 215: Materials Modification in Nanofabrication	Covers materials modification and addresses material growth and annealing, including rapid thermal annealing, and the impacts of thermal processing on defects, gettering, impurities, and overall electrical, mechanical, optical, and chemical properties.
ESCI 216: Characterization, Packaging, and Testing in Nanofabrication	Addresses nanofabrication characterization, packaging, and testing, emphasizing basic measurements for yield analysis and process control.

its nanofabrication degree program without the need for an articulation agreement with Penn State. Each community college “owns” the six courses of the capstone semester and uses them as they best serve that college’s students. The Penn State Nanofabrication Facility and its engineering staff are thus shared among all the members of the

Partnership in order to attain the goal of a well-educated, technician-level nanotechnology workforce.

The NMT Partnership is dedicated to preparing workers for the full range of nanofabrication applications, including biotechnology, pharmaceuticals, opto-electronics, information storage, materials manufacturing, and many others, as well as micro- and nano-electronics. By educating workers for the broad spectrum of nanofabrication applications, the NMT Partnership is also developing a Pennsylvania workforce that is less vulnerable to the business cycles of specific industries. Pennsylvania semiconductor workers have been vulnerable to periodic industry downturns. By broadening their skills through nanofabrication education, these workers gain the ability to move among industries as the needs for their skills evolve.

The experience of semiconductor workers makes them well qualified to enter nanofabrication training with little or no preparation. In addition, equipped with broad nanofabrication training, these workers represent an economic development opportunity for Pennsylvania. The Commonwealth of Pennsylvania and the NMT Partnership are now establishing a focused program for displaced semiconductor workers in the regions of the state hardest hit by the current industry downturn. As a result, roughly 25 percent of current capstone semester students are displaced electronics engineers seeking to broaden their skills. This focused program will provide easy access for these workers into the nanotechnology workforce.

The NMT Partnership also includes efforts to support professional development in nanofabrication for community college faculty members, and to promote the nanotechnology opportunity in secondary schools. Intensive, three-day professional

development workshops for educators and industry personnel have been offered annually at the Penn State Nanofabrication Facility since 1999. Like the capstone semester, the three-day professional development workshops include a mix of lecture and laboratory experience in the Penn State Nanofabrication Facility, and address a wide range of nanofabrication processes and applications. During 1999, the NMT Partnership also began offering three-day “chip camps” for middle school and high school students from across Pennsylvania. The chip camps provide secondary school students with an orientation to basic nanofabrication processes and applications, and the opportunity to observe these same nanofabrication processes in the Penn State Nanofabrication Facility.

The designation of the NMT Partnership as an NSF Center for Manufacturing Education in Nanofabrication is enabling a range of initiatives to strengthen this innovative educational partnership. These include continuous improvement and expansion of associate degree programs in nanofabrication, development of baccalaureate degree programs addressing nanofabrication, expanded student recruitment and industrial outreach, and improved governance of the Partnership, among others.

Increasing numbers of students are now coming into nanofabrication education programs at the community colleges from chemical engineering technology programs and life-sciences programs, as well as from electrical engineering technology programs. The NSF Center is enabling development and delivery of new courses and course modules at the community colleges that will better prepare students from these diverse educational backgrounds for the capstone semester.

The NSF Center for Manufacturing Education in Nanofabrication is also supporting the development of baccalaureate degree programs addressing nanofabrication

by the 14 comprehensive public universities of the Pennsylvania State System of Higher Education (SSHE). These universities are incorporating the existing 18-credit nanofabrication capstone semester into the first two years of existing baccalaureate programs in physics, chemistry, biology, or other appropriate fields. In addition, Penn State is working with the SSHE to develop two upper-division courses in nanofabrication, which will also be incorporated into the existing programs. This development of nanofabrication concentrations within existing baccalaureate degree programs in physics, chemistry, biology, and other fields will obviously enhance the career opportunities for these students; it also has the distinct advantage of providing clear pathways to baccalaureate degrees for students holding associate degrees in nanofabrication from community colleges.

Further, the new NSF Center for Manufacturing Education in Nanofabrication establishes a source of funding for each Pennsylvania community college and the Pennsylvania State System of Higher Education (SSHE) to support nanofabrication program development, student recruitment, industry outreach, participation in Center governance, and related activities. Before the creation of the NSF Center, no such funds were available and participation in the NMT Partnership by community colleges and the SSHE was supported entirely with the internal funds of these institutions. This NSF funding is allowing a substantially higher level of effort in Center activity by all of the participating institutions. Finally, the NSF Center is also supporting a focused effort to attract students from disadvantaged minority communities in Pennsylvania into nanofabrication education programs.

The Pennsylvania NMT Partnership and the new Center for Manufacturing Education in Nanofabrication are leveraging a \$25 million national research facility, and its engineering staff, at one of the nation's premier universities to strengthen educational programs at community colleges and other institutions in an emerging technology of strategic economic importance. The NMT Partnership is a proven success. Associate degree program graduates are receiving as many as seven offers for employment each, and salaries as high as \$52,000! The recent designation of the NMT Partnership as a NSF Center for Manufacturing Education in Nanofabrication will support continued expansion and improvement of this model program, and greater dissemination of information about its effectiveness to other educational institutions and regions of the country.