

The Pennsylvania Nanofabrication Manufacturing Technology Partnership: Resource Sharing for Nanotechnology Workforce Development*

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The Pennsylvania Nanofabrication Manufacturing Technology (NMT) Partnership was established in 1998 with support from the Commonwealth of Pennsylvania. Through the NMT Partnership, the \$25 million dollar equipment base of the Penn State Nanofabrication Facility and its staff are shared with community colleges and other Pennsylvania colleges and universities to enable these institutions to offer degrees in nanofabrication. In addition to providing semester-long, hands-on educational experiences for students from community colleges and other institutions, the NMT Partnership also offers professional development workshops in nanofabrication for educators, and nanofabrication 'chip camps' for middle and high schools students. This year, the NMT Partnership received a NSF award as a Regional Center for Manufacturing Education in Nanofabrication.

INTRODUCTION

THE PENNSYLVANIA Nanofabrication Manufacturing Technology (NMT) partnership originated as a state government response to the micro- and nanotechnology workforce and research needs of industry. Its guiding principle, since its inception, has been the sharing of the Penn State Nanofabrication Facility, a National Science Foundation National Nanofabrication Users Network site, with educational institutions across Pennsylvania. The nanofabrication workforce development effort began at the associate degree level and now also includes baccalaureate degree education. The NMT Partnership for nanotechnology workforce development has grown into a unique team effort involving over 30 institutions of higher education, secondary schools including vocational–technical schools, and private industry.

A BRIEF HISTORY OF THE NMT PARTNERSHIP

The Pennsylvania NMT Partnership was established in 1998, with the objectives of developing a nanotechnology workforce and nanotechnology-based industries for Pennsylvania. The antecedents of the NMT Partnership can be traced to the early 1990s when the concept for a nanofabrication users' facility began to take shape at Penn State.

Researches at Penn State and elsewhere recognized that nanotechnology education and research require access to facilities, equipment, and expertise that are too specialized and expensive to duplicate at every major research university or industrial research center with interest in the topic. As a result, in 1994, the National Science Foundation (NSF) created the National Nanofabrication Users Network (NNUN) with Penn State as a charter member, along with Cornell University, Howard University, Stanford University, and the University of California at Santa Barbara. National users' facilities were established at each of these universities as locations where academic and industrial researchers could have access to the equipment and engineering expertise needed to perform nanotechnology research. The Penn State Nanofabrication Facility began operating in 1994, serving both academic and industrial users. The facility has grown steadily since that time. In fact, the Penn State Nanofabrication Facility is the fastest growing of the five sites comprising the NNUN. Last year the facility was doubled in size to accommodate this growth.

Shortly after the Penn State Nanofabrication Facility began operating and external academic and industrial researchers began visiting the site, Penn State officials began to hear from industry visitors about the need for associate-degree level technicians skilled in micro- and nanofabrication. These concerns from industry presaged national science policy discussions about the shortage of science and engineering workers at all levels in the United States [1]. Many Pennsylvania companies

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were among those who worried that their growth prospects might be hampered by a lack of trained micro- and nanofabrication workers. Pennsylvania companies expressing these concerns represented the information storage, microelectronics, biotechnology, and optoelectronics industries, as well as nanofabrication equipment and supply vendors.

In 1997, Penn State proposed to Governor Tom Ridge that the Commonwealth of Pennsylvania provide funding for an educational initiative aimed at addressing the dearth of nanofabrication technicians. This proposal for a Pennsylvania NMT Partnership was supported by some of the most important high-technology employers in the state, and has received funding from the Commonwealth every year since 1998. Industry has guided every phase of the development of the NMT Partnership since its inception.

CREATING THE PARTNERSHIP

Higher education consortia are not new, but they are relatively few, and tend to be limited in scope. For example, consortia currently exist to provide for shared library collections [2, 3] joint purchasing [4] and joint management of university-industry research relationships [5]. Most of these education consortia tend to involve institutions of like kind [6, 7]. Higher education consortia involving dissimilar institutions, like leading research universities and community colleges, are uncommon, but do exist. Two examples are the Massachusetts Distance Learning Consortium [8] and the Michigan Virtual Automotive College [9]. The idea of addressing industry needs for technical workers through coalitions of two- and four-year higher education institutions is gaining important proponents [10]. A major challenge to the success of such heterogeneous higher education collaboration concerns the need to overcome the different cultures of the participating institutions [11].

Concepts of intergovernmental management can help explain how cultural and other barriers to collaboration have been overcome within the NMT Partnership. Intergovernmental management scholars argue that the design of government program administrative structures is shifting from hierarchical bureaucracies to multi-level partnerships [12, 13]. These partnership arrangements emerge from the symbiotic interdependence of the participating organizations whose members recognize the need for combined efforts in order to achieve things that would not be possible individually [14]. Further, a compelling 'program rationale' is a key feature that binds participants in intergovernmental management to collective effort [15]. These principles have guided the development of the Pennsylvania NMT Partnership.

Based on industry advice and concerns, the initial thrust of the NMT Partnership was on meeting the need for associate degree level nanofabrication technicians. Penn State, one of the

nation's leading research universities, does not specialize in the education of associate degree level technicians. However, Penn State houses the NNUN site and possesses the expertise needed for training nanofabrication workers. Pennsylvania's network of 14 community colleges, on the other hand, specialize in the education of associate degree level technicians but possess no nanofabrication facilities or expertise. Participants are thus bound to the NMT Partnership based upon the need for combined effort in order to offer an otherwise unattainable educational experience.

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 Nanofabrication Facility staff teach these six courses, called the 'capstone semester', for the community colleges. Community college students pay only their regular community college ('home 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.

The capstone semester was developed and is continuously improved with intensive industry oversight. One of the key features resulting from this industry involvement is an emphasis on hands-on laboratory experience. Students attending the capstone semester spend four hours each day in lecture and four hours conducting laboratory exercises in the Penn State Nanofabrication Facility. Penn State faculty members deliver the lectures. The laboratory experience is comprised of thirteen exercises designed to demonstrate and reinforce the lecture material. Clear and measurable objectives have been established for each laboratory exercise. Capstone semester students carry out the laboratory exercises working in teams of three to five students, with each team supervised by a Penn State graduate student.

Students are admitted to the capstone semester based upon the recommendation of a community college or other partner institution. Students entering the capstone semester are expected to have completed college-level courses addressing chemistry, algebra, statistics, and physics, and to possess college-level writing skills and computer literacy. A grade point average of 2.5 or higher in prior college course work is required. Students are expected to have demonstrated regular class attendance and ability to follow directions and complete assignments on time. Team learning is heavily emphasized during the capstone semester. Therefore, students are also expected to possess interpersonal communication and conflict resolution skills.

The capstone semester is taught in three five-week segments of two courses each. The first

course provides an overview of basic nanofabrication processing equipment and materials handling procedures with a focus on safety, environment, and health issues.

The second course provides an overview of the equipment and processes used to fabricate devices and structures such as complementary metal-oxide-semiconductor (C-MOS) transistors and power devices, microelectromechanical (MEM) devices, and biomedical devices including 'lab-on-a-chip' structures.

The third course 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.

The fourth course 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, e-beam lithography and advanced optical lithographic techniques.

The fifth course 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.

The sixth and final course addresses nanofabrication characterization, packaging, and testing, emphasizing basic measurements for yield analysis and process control.

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 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 shared among all the members of the Partnership to attain the goal of a well-educated, technician-level nanotechnology workforce.

All nanofabrication associate degree graduates from Pennsylvania institutions have experienced this six-course capstone semester at the Penn State Nanofabrication Facility. These six courses include four 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 a 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 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 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. These include silicon diode processing, material growth, oxidation, lithography, ion implantation, diffusion, chemical vapor deposition, etching, metallization, assembly and testing, and applications to microelectromechanical systems, optoelectronics, microelectronics, and biotechnology.

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 those same nanofabrication processes in the Penn State Nanofabrication Facility. These students learn about physical and chemical vapor deposition, lithography, plasma etching, thermal modification of materials, and applications of these nanofabrication processes to microelectronics and biotechnology. The chip camps also address educational and career opportunities in nanofabrication, and include recreational activities. The chip camps require a company, school, or church, or a community or professional organization, to step forward to organize and select a group of 'campers' at the local level. Penn State staff then schedule the visit to the Nanofabrication Facility, arrange for dormitory space and recreational activities at Penn State, and provide the teaching that opens the door to the world of nanotechnology.

CURRENT STATUS: THE NANOTECHNOLOGY WAVE

The microelectronics industry, one of the key creators of the nanotechnology revolution, remains the biggest user of micro- and nanotechnology. This industry, with transistors in everyday production that are the size of virus molecules and devices in the laboratory that are literally molecules, is approaching the point where it may be more properly termed the nanoelectronics

industry. However, many other industries are now also using nanotechnology, including biotechnology, pharmaceuticals, optoelectronics, information storage, and materials manufacturing.

The NMT Partnership is dedicated to preparing workers for this full range of nanofabrication applications. Efforts are well underway to ensure that community college associate degree programs in biology, chemistry, and other fields provide students with the background needed for the hands-on capstone semester at the Penn State Nanofabrication Facility. In October 2000, the National Science Foundation provided substantial support for these efforts by granting Penn State and the Community College of Philadelphia a Partnership for Innovation award to assess biotechnology and pharmaceutical industry applications of nanofabrication, to aid companies in these industries in the use of nanotechnology, and to develop community college curricula to meet associated workforce development needs.

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 economic cycles of specific industries. Pennsylvania semiconductor workers have been vulnerable to the 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. Semiconductor workers are among the very best candidates for nanofabrication training due to their backgrounds. 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. This focused program will provide easy access for these workers into the nanotechnology workforce via Pennsylvania community college nanofabrication programs and the capstone semester.

The NMT Partnership has been an overwhelming success to date. Associate degree program graduates are receiving as many as seven offers for employment each, and salaries as high as \$52,000. Industry advisors to the NMT Partnership stress that it is the hands-on education in the Penn State Nanofabrication Facility that makes the students so valuable. Cathleen Barton, Director for Workforce and Education Strategy at the Semiconductor Industry Association, has stated, 'Pennsylvania's NMT Partnership helps position Pennsylvania as an ideal location for new industrial nanofabrication facilities in the years ahead.' In addition, students enrolled in nanofabrication programs of the NMT Partnership report high levels of satisfaction with the educational experience. In surveys completed by students completing the capstone semester in nanofabrication, more

than 88 percent rated the quality of the lectures and the laboratories either high or very high.

LOOKING FORWARD

On July 9, 2001, the National Science Foundation designated the Pennsylvania 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. The designation of the NMT Partnership as an NSF Center for Manufacturing Education in Nanofabrication will enable a range of initiatives to strengthen this innovative educational partnership. These include the development of baccalaureate degree programs addressing nanofabrication, continuous improvement and expansion of associate degree programs in nanofabrication, increased outreach to secondary school students, and improved governance of the Partnership.

Through the new NSF Center for Manufacturing Education in Nanofabrication, the Pennsylvania State System of Higher Education (SSHE) as well as each of the fourteen participating community colleges will receive annual NSF funding through the Center to support nanofabrication program development, student recruitment, and related activities. Also, the NMT Partnership advisory board is being expanded to include representatives from the SSHE institutions and increased industry representation from the biotechnology and pharmaceutical industries.

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 will enable development and delivery of new courses and course modules at the community colleges that can better prepare students from these diverse educational backgrounds for the capstone semester. In addition, new course modules that provide an introduction to nanofabrication will be developed through the NSF-funded Center. These will also be aimed at better preparing students from various backgrounds for the capstone semester and will be created for students in both the associate and baccalaureate degree programs. These new course modules will be shared among the community colleges and four-year institutions and delivered through distance education technology whenever appropriate.

The need to attract greater numbers of secondary school students to community college degree programs in nanofabrication was recognized early in the development of the NMT Partnership. As has been noted, the NMT Partnership has supported summer chip camps for secondary school students each year since its inception aimed at promoting careers in nanofabrication.

Special efforts have also been made to increase participation by underrepresented groups in chip camps. Despite these efforts, it has proven difficult to attract young people into the nanofabrication degree programs. This is surprising given the lucrative career opportunities promised by nanofabrication training, and reflects the broader decline in interest among students in science and engineering [16]. Special efforts will be undertaken through the new NSF-funded Center to increase awareness about nanotechnology among secondary school educators and guidance counselors. Direct outreach to secondary school students will also be increased.

A recent effort sponsored by the Pennsylvania Department of Education to develop pathways through which vocational-technical school students can matriculate to community college, nanofabrication degree programs will be expanded. Efforts to be undertaken include development of secondary certificate programs in nanofabrication at vocational-technical schools that prepare students for entrance to community college programs at advance placement levels, and creating opportunities for regular, periodic communication among faculty members and administrators at vocational-technical schools, other secondary schools, community colleges, and other post-secondary institutions concerning nanofabrication education.

The NSF Center for Manufacturing Education in Nanofabrication will support the development of baccalaureate degree programs addressing nanofabrication by the Pennsylvania State System of Higher Education (SSHE) through the new SSHE Center for Applied Nanotechnology. This newly created SSHE organization is composed of representatives of the 14 comprehensive public universities that comprise the SSHE. These universities will incorporate 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 will work 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, and it also has the distinct advantage of providing clear pathways to baccalaureate degrees for students holding associate degrees in nanofabrication from community colleges.

CONCLUSIONS

In its 1999 report, the Kellogg Commission on the Future of State Related and Land Grant Universities recommended that public institutions of higher education adopt a model of 'institutional engagement' that integrates traditional teaching, research, and service activities to become more sympathetically and productively involved with the communities they serve [17]. The Pennsylvania NMT Partnership exemplifies the concept of institutional engagement.

The Pennsylvania NMT Partnership is leveraging a \$25 million national research facility and its 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 has overcome traditional cultural and other hurdles to higher education collaboration, and has leveraged state and federal funding to support continued expansion. The NMT Partnership is a model of higher education institutional engagement for the nation, and one that can and should be replicated in other educational fields and regions of the country. The recent designation of the NMT Partnership as a NSF Center for Manufacturing Education in Nanofabrication will support greater dissemination of information about this model program to other educational institutions and regions of the country.

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