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PLANNING A NSF ATE NATIONAL CENTER IN NANOMANUFACTURING EDUCATION

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Over the past decade, microfabrication has been subsumed by nanofabrication, and it is estimated that the United States will need between 800,000 and 1 million new nanofabrication workers in the next 10 years (Breslau, 2002; Roco, 2002). Several industry sectors are driving this workforce need. First are the established industries that traditionally use micro- and nanotechnology, such as microelectronics, information storage, optoelectronics, and others. Second are industries that have been newly created by this technology, such the MEMs, NEMs, nanobiotechnology, and nanoelectronics start-ups. A third driving sector is composed of existing major industries that previously have never used micro- and nanotechnology but are now actively embracing it (Siegel, 1999). Among these are giants such as the pharmaceutical and chemical industries, and even more traditional industries like clay and glass.

Workers with skills in micro- and nanofabrication are needed at all levels. At the more advanced levels (engineers and above), workers are needed with specialized skills. At the technician level, however, where the majority of new nanofabrication jobs will be, a generic skill set is needed. The skill set needed at the technician level is identical for companies using micro- and nanotechnology whether they are producing electronic, electromechanical, biological, chemical, or any other kind of system. With this single skill set approach, students are given a background that allows them to move back and forth across industry sectors, as micro- and nanotechnology evolves and new opportunities arise. By educating students across the broad spectrum of nanofabrication applications, we develop a workforce that is more versatile and less vulnerable to the business cycles of specific industries.

Curriculum addressing the generic skill set needed for technician-level micro- and nanofabrication workers has already been developed and is being continuously improved by the existing NSF Advanced Technology Education (ATE) Regional Center for Nanofabrication Manufacturing Education, established in July 2001. With support from NSF and the Commonwealth of Pennsylvania, the Regional Center for Nanofabrication Manufacturing Education today supports associate degrees in nanofabrication (the first such programs in the nation) at every Pennsylvania community college as well as several Penn State campuses and other institutions, professional development of educators and industry personnel, K-12 education, and most recently, development of nanotechnology baccalaureate degree programs at Pennsylvania State System of Higher Education (SSHE) universities and at Penn State.

The key feature of the Center that enables Pennsylvania community colleges and other partner institutions to offer degree programs in nanofabrication is a suite of six nanofabrication courses taught three times per year (fall and spring semesters and summer session) at the $33 million, Penn State Nanofabrication Facility, part of the NSF-sponsored National Nanofabrication Infrastructure Network (NNIN). The capstone

semester was developed and is continuously improved with extensive industry oversight, and receives funding support form the Commonwealth of Pennsylvania.

Since its creation, the ATE Regional Center for Nanofabrication Manufacturing Education has grown into a unique team effort involving more than 30 colleges and universities, secondary schools, and private industry. Senior officials of the National Science Foundation repeatedly cite the Center as a model for other states and nations. The Center has firmly established Pennsylvania as the national leader in nanotechnology education and training (See: Hallacher, Fenwick, and Fonash, 2002; Fonash, 2001). The major activities and accomplishments of the Center are summarized on Table 1.

Table 1
NSF ATE Center for Nanofabrication Manufacturing Education Activity Summary
October 2003

Institutions offering nanofabrication associate degree programs	20
Nanofabrication associate degrees awarded to date	113
Students enrolled in nanofabrication associate degree programs	120
Institutions offering nanofabrication baccalaureate programs	3
Nanofabrication baccalaureate degrees awarded to date	2
Students enrolled in nanofabrication baccalaureate degree programs	5
Pennsylvania companies employing nanofabrication program graduates	24
Nanofabrication program graduates employed in Pennsylvania	65
Nanofabrication program graduates employed outside Pennsylvania	9
Students enrolled in the current nanofabrication capstone semester	14
Students enrolled in the upcoming nanofabrication capstone semester	12
Educators that have completed professional development workshops	270
Industry personnel that have completed professional development workshops	275
Secondary students that have completed *Nanotech Camps*	479
Career and Technical Institutes participating in 2+2+2 nanofabrication education pathways	41

As indicated, 113 students have graduated to date from the associate degree programs in nanofabrication at Pennsylvania community and technical colleges. Complementing these programs, 2+2+2 nanofabrication education pathways have been established linking 41 secondary-level Career and Technical Institutes to community college associate degree programs and baccalaureate programs. To promote the 2+2+2 pathways, the NMT Partnership offers enormously popular summer *Nanotech Camps* for middle and high school students (grades seven and above) at the Penn State Nanofabrication Facility. To date, 479 students have attended *Nanotech Camps*. In addition, intensive, three-day professional development workshops for educators and industry personnel have been offered continuously at the Penn State Nanofabrication Facility since 1999. To date 270 Pennsylvania educators and 275 industry personnel have attended these workshops.

Educational programs of the Center are continuously evaluated. Students complete detailed assessments during the capstone semester in nanofabrication, and are periodically surveyed for several years following completion of the semester. Attendees at nano camps and professional development workshops also complete assessments as

part of their educational experiences. In 2002-2003, a comprehensive assessment of the capstone semester in nanofabrication was conducted by the Penn State College of Education. The assessment was conducted for two purposes: (1) identify the competencies and characteristics that are needed for incoming students to succeed in the capstone semester; and (2) assess the alignment of the capstone semester outcomes with expectations of industry.

The initial results of this study have already been used in a variety of ways. For example, a standard process is now being used to certify that prospective students possess the academic experience and personal characteristics necessary for success in the capstone semester. The results have also been used to improve the design of capstone semester instructional material and laboratory experiences, and to strengthen the classroom interaction and teambuilding that takes place as part of the capstone semester learning experience.

Efforts to assess the alignment of the capstone semester outcomes with industry expectations involve two activities. First, a study was undertaken to examine whether the curriculum of the nanofabrication capstone semester is being taught as it has been outlined based upon industry needs. To conduct this study, the Center worked with the NSF sponsored MTS (Materials Development, Training, and Support Services) program of the Western Michigan University Evaluation Center. This study found "that this is a very robust program, what it sets out to do and more. It provides students with a sound background in nanofabrication with ample hands-on laboratory experience. The program appears to be forward looking, so that students are exposed to the most current trends in the field."

Second, a series of interviews have been conducted with employers who have hired or plan to hire nanofabrication associate degree program graduates. Table 3 lists the employers that were interviewed as part of this study. These companies span the full range of industries using micro- and nanotechnology, including semiconductor, information storage, chemical, biotechnology, and other types of companies. Six of these nine employers have hired nanofabrication program graduates, and four of them employ more than one graduate.

Table 3
Employers Interviewed in Evaluation of Capstone Semester in Nanofabrication

Employer	Micro- or Nanotechnology Application
Air Products and Chemicals, Inc.	Chemicals for semiconductor manufacturing
Ashland Chemical Company	Chemicals for cleaning semiconductor equipment
Fairchild Semiconductor	Power semiconductors
NanoHorizons	Biological detection and screening devices
National Institute of Standards and Technology	Semiconductor metrology
Penn State Nanofabrication Facility	Nanotechnology research
Seagate Technology	Information storage
Verimetra, Inc.	MEMS devices for medicine
Xactix, Inc.	MEMS manufacturing equipment

These employers agreed that no other program offers what the Center for Nanofabrication Manufacturing Education provides, and that the hands-on capstone semester in nanofabrication provides students with a broad skill set valuable to any

company using micro- or nanotechnology. One employer stated, "We call these people 'super technicians' because they can hit the ground running in so many different fields." Another stated, "One graduate moved from orientation to unsupervised shift work in three weeks, the fastest of any technician hired in a similar position." A conclusion from this study is that the Center is successfully providing students with a generic skill set that is applicable across the range of industries using micro- and nanotechnology.

The growing demand for associate degree level technicians with micro- and nanofabrication skills suggests that there is a need for a national ATE center addressing this area. Based on this, leaders of the Regional Center for Nanofabrication Manufacturing Education at Penn State, in partnership with the Harrisburg Area Community College in Pennsylvania and Corning Community College in New York, requested funding from the NSF in fall 2002 to support planning for such a national center. A fundamental argument in this proposal was that because the skill set needed at the technician level is common across the various industries that are applying micro- and nanofabrication, a single, unifying center to crucial to discourage the proliferation of applications-focused micro- and nanofabrication technician educational programs. The NSF ATE project *Planning for a National ATE Center in Micro-and Nanoscale Manufacturing* was awarded in June 2003.

The first step in the planning process was to identify potential industry and education partners for a national center. The Regional Center for Nanofabrication Manufacturing Education has maintained an active industry advisory board since inception, and hosts job fairs involving dozens of companies three times each year. The industrial users of the 12 NNIN sites represent another cadre of companies that have interest in micro- and nanofabrication technician education. Two NSF Partnership for Innovation studies already been carried out by Penn State and the University of Pennsylvania identify dozens of pharmaceutical and biotechnology companies with interest in micro- and nanotechnology. Existing ATE centers such as MATEC and BIOLINK also have extensive contacts with companies that have interest in micro- and nanofabrication technician training. National laboratories specializing in micro- and nanotechnology research, such as NIST, Sandia, and Los Alamos, similarly have extensive industry ties that can be leveraged. By leveraging these and other relationships, hundreds of companies with interest in micro- and nanofabrication are being catalogued nationally.

Colleges and universities in Arizona, California, Georgia, Minnesota, New York, Wisconsin, Texas, and other states are participating in the planning process based on interest in joining a national ATE center for micro- and nanofabrication education. These educational institutions are being identified through organizations such as the American Association of Community Colleges, the NSF ATE program, the NSF NNIN, and other sources. All interested educational institutions are being given to the opportunity to engage in information exchange concerning ways to address the national need for trained micro- and nanofabrication technicians and invited to participate. Three to four regional meetings around the nation are being held in spring 2004 to organize industry and educational institutions with interest in micro- and nanofabrication technician training.

The experience of our NSF Regional Center for Nanofabrication Manufacturing Education has shown that a key feature for effective education of technicians in micro- and nanofabrication is access state-of-the-art clean rooms and processing equipment. Thus, an inventory of micro- and nanofabrication user facilities across the country that might be available for such educational purposes is also being undertaken. Some of the facilities

already identified as available for educational purposes include several of the NSF sponsored NNIN sites, Department of Energy sponsored facilities associated with Los Alamos and Sandia National Laboratories in New Mexico, U. S. Army sponsored facilities at MIT in Massachusetts, and others. A comprehensive inventory of micro- and nanofabrication user facilities, with an assessment of the degree to which each might be made available to support technician training, is being compiled.

The inventory of nanofabrication facilities available for educational purposes makes it clear that use of a centralized, nanofabrication facility that supports technician-level education programs at multiple institutions within a region may not be appropriate or even feasible everywhere. Therefore, alternative approaches, such as computer-based laboratory exercises, or hands-on laboratory exercises with more modest facility requirements, are also being investigated. The aim is to identify "best practice" alternatives to the "centralized facility" approach for use in regions where a centralized facility is not available. The assessment involves cataloguing alternatives to the "centralized facility" approach and identifying strengths and weaknesses of each via interviews with employers. The most preferred feasible alternative appears to be development of laboratory exercise kits that can be used at an educational institution with a set of instruments that can be acquired for less than $100,000, supplemented with periodic field trips by students to micro- or nanofabrication facilities.

The planning project will culminate in mid 2004 with a national meeting involving representatives of industry, educational institutions, and micro and nanofabrication user facilities across the country having interest in establishing a NSF ATE National Center in Micro- and Nanoscale Manufacturing. This group will make a final assessment of the feasibility of such a national approach. Criteria for this assessment will include the level of interest among the participants, the level of resources the participants are willing to commit, and the willingness to collaborate toward a joint strategy for achieving such a vision.

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