Nanotechnology Education at SUNY Poly

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Abstract

Over the last decade, New York State has become a hub of nanotechnology for the east coast and one of the leading centers in the country in this field. The creation of new nanoelectronics facilities and the expansion of others has generated a need for highly skilled, yet adaptable work force to support the staffing needs of the nanotechnology industry. A new Computer Chip Commercialization Center (Quad-C) on SUNY Polytechnic Institute (SUNY Poly) campus in Utica, is part of the sprouting industry and alone is expected to create approximately 1500 direct jobs.

The intent of this paper is twofold. On one side it explains the rationale for recent changes to the requirements for the Nanotechnology minor while on the other side it explores the opportunities for the expansion of the nanotechnology education that arise through the integration of SUNYIT and CNSE into a single academic entity, SUNY Poly.

The College of Engineering through its Engineering Technology Department in Utica has engaged in a curriculum rejuvenation consisting of the creation of new course content, new course development, efforts to develop a new nanocharacterization laboratory, and cooperation with the Colleges of Nanoscale Science and Engineering (CNSE) in Albany. These efforts have been translated into the enhancement of a Nanotechnology minor program. These initiatives have attracted the interest of a significant number of students and enhanced the educational programs at SUNY Poly in Utica.

Introductory college course in Physics and Chemistry are prerequisite courses for the Nanotechnology minor. The minor requires a minimum of 17 credits including a Core Course and four Elective Courses. The Core Course surveys the broad field of nanoelectronics and nanodevices bringing familiarity with the essential technologies and enabling the understanding of the various study paths that students can follow. Elective Courses include Micro and Nano Electro-Mechanical Systems, Nanoscale Materials, Semiconductor Microfabrication, Process Control and Design of Experiments, and Thin Film Processing.

Introduction

The semiconductor industry has been one of the main engines of the U.S. economy, being the third largest contributor to the U.S. GDP, by adding annually more than $65 billion to the U.S. economy, according to the Bureau of Economic Analysis[1]. Over the last few years with billions of dollars in combined investments between the state of New York and leading international companies, the footprint of the nanotechnology industry has been expanded at a sustained pace creating a strong demand for a trained workforce. The most recent examples of the successful expansion of the nanotechnology industry in upstate New York are the continued work on the Computer Chip Commercialization Center (Quad-C) at SUNY Polytechnic Institute in Utica and on the Zero Energy Nanotechnology (ZEN) building in Albany, both scheduled for completion in 2015.

In this context, the curricula existent at SUNY Poly in Utica was found in a dire need for an update, to keep pace with the advancements in the industry. A set of courses, with a total of 20 credit hours, constituting a minor in Nanotechnology were being offered already. However, its structure was deemed deficient as typical prerequisite courses (General Physics, Essentials of Chemistry, Introduction to Biology – 8 credits) were part of the minor credit hour count. The rest of the courses adding up to 12 credits were as follows: Introduction to Nanotechnology, Fundamentals of Microelectromechanical Systems (MEMS) and Nanoelectromechanical Systems (NEMS), Material Science Applications, and Nanotechnology Research. We have therefore developed new courses and content to reform the Nanotechnology minor program. One challenge of this undertaking is to provide sufficient breadth and depth of the knowledge within the limited boundaries of a minor program with a Nanotechnology focus. Although currently the Utica campus of SUNY Poly does not have its own nanotechnology laboratory, it is in the process of renovating laboratory spaces and purchasing material characterization and analysis equipment.

SUNY Poly Programs

SUNY Poly is an institution with two sites, and both have a curriculum with a focus on nanotechnology: The College of Engineering in Utica offers a minor in nanotechnology while the nanotechnology education can be continued and expanded at the Colleges of Nanoscale Science and Engineering in Albany with masters and doctoral studies. The College of Engineering through its Engineering Technology department is engaged in administering the nanotechnology related courses in Utica. As an interdisciplinary subject, nanotechnology has many facets reflecting knowledge from various engineering areas: electrical, mechanical, chemical, biology, etc. Therefore, faculty from the electrical engineering and mechanical engineering technology programs has started to collaborate since the fall of 2014 to bring this breadth of information under the nanotechnology minor umbrella. Although the program is geared specifically toward students in the technology and engineering areas - most of the enrolled students are from electrical and mechanical technology programs – a few of the courses have a general character suitable for students from other areas of education with an interest in nanotechnology.

Minor in Nanotechnology

The nanotechnology minor is designed to provide knowledge and skills valuable to students planning to seek employment in fields such as semiconductor manufacturing, microelectronics, optoelectronics, information storage, medicine, pharmaceuticals, and cosmetics. In addition, the minor also prepares students for graduate studies where various research opportunities could bring familiarity and hands-on experience in the nanotechnology field of choice.

Knowledge of Physics and Chemistry is central to every engineering and technology field, and so these are prerequisite courses for the Nanotechnology minor. The minor requires a minimum of 17 credits, althoughthe typical study path would have 20 credit hours including one Core Course and four Elective Courses, as represented in Table 1.

Table 1: Nanotechnology Minor Curriculum

Level	**Courses**
Freshmen/Sophomore Level – Core course	Introduction to Nanotechnology
Junior Level – Elective course	Semiconductor Microfabrication
Junior Level – Elective course	Micro and Nano Electro-Mechanical Systems
Junior Level – Elective course	Nanoscale Materials
Senior Level – Elective course	Thin Film Processing
Senior Level – Elective course	Process Control and Design of Experiments

Couse Descriptions

Introduction to Nanotechnology

The Core Course surveys the broad field of nanotechnology bringing familiarity with the essential technologies and enabling the understanding of the various study paths that students can follow. The nanotechnology introductory course is presented as an inclusive survey of the major techniques, methods, concepts and materials that overlap in the nanotechnology field and is organized in four sections:

1. Introduction to nanoscale, Structure of Matter - the Atomic Model
2. Methods and instruments for visualization of nanostructures and characterization of their properties:
   2.1. Atomic Force Microscopy: Principles of operation, Constructive elements, Imaging modes, Advanced imaging techniques, Nanofabrication using AFM.
   2.2. Electron microscopy: Observation limits using light, Electron sources, Constructive elements of the scanning electron microscope (SEM), Imaging and material analysis with SEM, Transmission electron microscope.
   2.3. X-ray diffraction: What are x-rays and how are produced, Wave interference and Bragg law, X-ray diffractometer and diffraction techniques.
3. Nanostructures and physical methods for nanostructure fabrication: Top-down methods - Photolithography, Focused Ion Milling. Bottom-up methods: Thin film growth and growth modes, Steps of thin film growth, Vapor-liquid-solid growth, Chemical vapor deposition, Thermal oxidation of silicon, Physical vapor deposition, Molecular beam epitaxy, Atomic layer deposition.

4. Nanostructure applications: solid state light sources, nanostructured solar cells, sensors, MEMS, Fullerenes and carbon nanotubes, composite materials. Safety: toxicology and workplace policies.

The lectures are supplemented with a weekly one hour of Virtual Nanolab where selected video clips featuring detailed demonstrations of the characterization methods and processing techniques are presented.

Semiconductor Microfabrication
The course introduces processes specific for the Silicon fabrication of VLSI circuits. The study topics include: crystal growth and crystal structure and processes such as chemical vapor deposition (CVD) growth, thermal oxidation, etching, metal deposition diffusion, ion implantation, and photolithography. Process integration, MOS transistor fabrication, yield and reliability are also introduced.

Thin Film Processing
The course focuses on the main aspects of the thin film synthesis: the fundamentals of crystal structures, the basic nucleation and growth mechanisms. Other topics studied include processes and technologies used for the thin film fabrication such as: chemical vapor deposition (CVD), Metal-organic CVD, molecular beam epitaxy (MBE), Plasma Assisted-MBE, sputtering, evaporation etc., thin film growth equipment operation principles and the fundamentals of vacuum technology and gas delivery systems. Techniques for the monitoring and characterization of thin film parameters during the growth (in-situ) and after the growth (ex-situ) are also analyzed.

Nanoscale Materials
The fundamental aspects of Nanoscale materials are introduced, including electronic states and electrical properties and optical properties. The course studies the interactions of nanoscale materials with charged particle and electromagnetic waves, ultrafast dynamics of metal nanoparticles, magnetic and magneto transport properties.

Micro- and Nano Electromechanical Systems
The course introduces the student to the emerging field of Microelectromechanical systems (MEMS) and to the more advanced level of miniaturization known as Nanoelectromechanical Systems - NEMS. Topics include introduction of physical scaling laws, essential electrical and mechanical concepts, methods of fabrication and packaging of MEMS, principle of micro-actuation, emergence of nanoscale systems, visualization, and applications of micro and nano systems.

Process Control and Design of Experiments
The philosophy of quality control and fundamental quality tools is exposed in this course, including process flow diagrams, control charts for variable measurement, process sampling and

chart interpretation. Methods for process optimization through single and multiple factor experimental designs are also introduced.

Textbook Selection

Textbook selection has turned out to be a challenge with multiple sources. The challenges are related to the novelty of the field, the fast pace of the changes and additions in concepts and applications as new knowledge becomes available almost daily and the limits of the undergraduate students educational background.

The text books that aim at introducing the reader to the nanotechnology field reflect the diversity of the approaches the authors can elect based on their field of expertise. Thus there are texts with an accent on bionanotechnology while others have a strong focus on quantum phenomena and electronic devices. Some are a light touch on “everything” while others are addressing readers with a solid physics background. Thus the challenge was to select a balanced presentation of the topics in the nanotechnology arena. Regardless of the textbook choice, we are aware that it will have to be revisited periodically and replaced with a better text when it becomes available. Further, we are augmenting the textbook with up to date information collected from reputable publications (i.e., Nature Nanotechnology, Nano Letters, etc.) and from the research reports of our institution. Currently the introductory text selected for nanotechnology is “Nano: The Essentials – Understanding Nanoscience and Nanotechnology”, T. Pradeep, Tata McGraw-Hill 2007. The complete list of the textbooks that we use for the courses in the nanotechnology minor is presented in the Table 2.

Table 2 - list of the textbooks used for the courses in the nanotechnology minor

Course	**Textbook**
Introduction to nanotechnology	Nano: The Essentials – Understanding Nanoscience and Nanotechnology, T. Pradeep, Tata McGraw-Hill 2007
Semiconductor Microfabrication	Introduction to Microfabrication, 2nd edition, S. Franssila, Wiley, 2010
Thin Film Processing	Materials Science of Thin Films, 2nd Edition, Milton Ohring, Academic Press, 2001
Nanoscale Materials	Nanoscale Physics for Material Science, T. Tsurumi, H. Hirayama, M. Vacha and T. Taniyama, CRC Press. Taylor & Francis Group, 2010
Micro- and Nano Electromechanical System	Foundations of MEMS 2nd edition, Chiang Liu, Prentice Hall 2012
Process Control and Design of Experiments	Quality Management for Organizational Excellence: Introduction to Total Quality, 7th edition, D. L. Goetsch, Prentice Hall, January 13, 2012 Creating Quality: Concepts, Systems, Strategies, and Tools, W.J. Kolarik, Mcgraw Hill Series in Industrial Engineering and Management Science, 1995

Outreach activities

In order to attract students to the nanotechnology minor program we have developed a brochure to be used for advertising purposes by our marketing and enrolment department, Fig.1. Furthermore, we have established contacts with high school teachers in the area (i.e. Clinton High School, Proctor High School) providing information and guidance regarding the nanotechnology field, activities, safety aspects and the industry trends in the upstate New York. With their help we hope that more students will feel compelled to enroll to science and engineering programs of SUNY Poly.

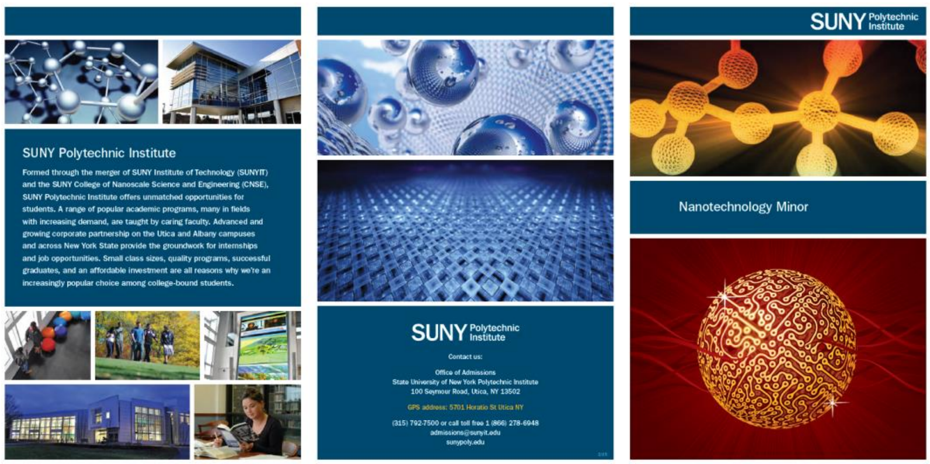

Figure 1. Nanotechnology minor brochure.

Undergraduate and Graduate Programs

The Colleges of Nanoscale Science and Engineering (CNSE) are at the center stage of the nanotechnology education in SUNY Poly. Together they offer comprehensive baccalaureate, master of science and doctoral programs in Nanoscale Science and Engineering. The cross-disciplinary character of the nanoscale scientific concepts has been supported through the creation of a constellation of “think-tanks” that include faculty from complementary science and engineering fields, such to encourage and stimulate cross-disciplinary educational curricula and research programs. These constellations support the following areas of study: Nanoscience, Nanoengineering, Nanoeconomics and Nanobioscience. Thus the degrees offered are on selected science and engineering tracks relating to the nanoelectronic, optoelectronic, optical, nano/micro-electro-mechanical, nano/micro-opto-electro-mechanical, energy, and nanobiological fields. Both the bachelor's degree in nanoscale engineering and the bachelor's degree in nanoscale science offer an academically rigorous instructional path with 128 credit hours of study, based on more than 50 courses spanning over various aspects of the nanotechnology and allowing the students to develop substantive capstone research projects. The undergraduate and graduate curricula couples the intellectual and technological resources of CNSE's NanoTech

Complex. CNSE is pioneering an institutional model that integrates closely the educational activity of the students with the academic and industrial research. This concept offers multiple advantages. Among them it provides access to state-of-the-art technologies, equipment, and processes, expanding the range of research that can be undertaken along the educational instruction. In return, the industrial partners benefit from a talent pool from which they can select collaborators with unique competencies, future employees and in general, a skilled work force that is accustomed with the latest technology. For example, CNSE complex houses the only fully-integrated, 300 mm and 450 mm wafer, computer chip pilot prototyping and demonstration line within 80,000 square feet of Class 1 capable cleanrooms. The industrial partners operating at CNSE, include IBM, AMD, ASML, Applied Materials, Tokyo Electron, and LAM Research.

CNSE is also home to a couple of unique initiatives that build on the successful example of academia-industry collaboration. The New York State Center of Excellence in Nanoelectronics, is a fully integrated research, development, prototyping, pilot manufacturing, and education resource with state-of-the-art laboratories, and shared-user facilities between the College research groups and industry partners and an array of research centers. Students and faculty work alongside scientists from industry and other institutions on fundamental cutting-edge research underlying real-world problems that most concern industry.

Another major focus at CNSE, reflected by its graduate program curriculum, is to introduce nanotechnology applications to the energy and environmental industries. The goal of the energy center is to leverage nanotechnology and infrastructure to support advances in energy subdomains such as energy storage, energy efficiency, renewable power generation, and environmental industry. The U.S. Photovoltaic Manufacturing Consortium (PVMC) at CNSE is another development which is supported by the US DOE SunShot Initiative. PVMC is an industry-led consortium for cooperative R&D among industry, university, and government that partner to accelerate the development, commercialization, manufacturing, field testing, and utilization of next-generation solar photovoltaic (PV) systems. In support of the solar photovoltaic education advanced courses such as Nanotechnology and Photovoltaics, Renewable and Alternate Energy Nanotechnologies, Nanoelectrochemical Systems, etc. are offered. Through CNSE's technology programs, advanced manufacturing development facilities, system demonstration, and reliability and testing capabilities, PVMC is providing student training and serves as a proving ground for innovative solar technologies and manufacturing processes. This program also serves as a place to establish long term collaboration with industrial partners, who usually offer many intern positions to students for training during summer.

Collaboration

With research facilities that are cutting-edge and unparalleled in the academia, the collaboration between the faculty members at the two campuses should bring opportunities to extend the potential benefits of this technological base to the students in Utica. Two modes of collaboration have been identified and discussed. Under one mode, the collaboration between students at one site and faculty on the other site is remote, and the interaction is ensured through technology-mediated communication. Under this type of collaboration the elective course offering for the Nanotechnology minor at Utica can be expanded gradually, benefiting from the large number of Nanoscale centered courses available in Albany. The ultimate goal of the collaboration is to enable the development of the nanotechnology education into a major program: Nanoscale Engineering Technology. The courses can be developed in synchronous or asynchronous modes, to accommodate scheduling needs for both students and faculty. The need for experiential learning could be ensured also remotely. The remote mode would be mediated by an instructor (at Utica site) while the technician (Albany site) would supervise the equipment setup and sample loading/un-loading in the remote-operated characterization equipment. Most of the equipment available in the prototyping and demonstration line in Albany site can be accessed remotely via Internet. As such, no physical presence is required to develop, submit and run a process recipe to deposit a layer or even to fabricate a device.

A second mode of collaboration features periodic seminars with the participation in Utica of the research faculty from Albany. The purpose of the seminars will be to share information regarding the ongoing research in the field of Nanotechnology and views regarding the technology trends. Summer seed grants are planned to stimulate the collaboration between faculty members from the two sites. The research activity associated with these grants will be performed in Albany and will allow the development of preliminary project data that could constitute the foundation of joint state or federal grant applications. Such collaboration, founded on common research interests has been started already and has produced preliminary common research proposals. Activity to generate experimental data in support of these proposals has been planned for the summer of 2015. If successful, this activity can constitute a proof for the concept viability, despite the geographical distance between the Utica and Albany sites.

Conclusions

The development of the nanotechnology into one of the most important economic drives of the 21st century has been supported by the creation of a significant industrial infrastructure in the state of New York. The importance of this economic sector is best reflected in the multi-billion dollar National Nanotechnology Initiative[2] that supports the creation of the laboratory and human resource infrastructure in universities to prepare the workforce for the 21st century innovation economy. In this perspective, a curricular restructuring has been enacted at SUNY Poly in Utica through the minor in nanotechnology that could stand to benefit in the future from the material and expert support available at CNSE in Albany. These efforts have been successful in creating up to date curricula, providing expertise in the Utica community and new learning opportunities for students. These initiatives are essential in developing new generations of engineers able to operate and innovate in a highly technologized and competitive industry.

References

1. M. Parpala, The U.S. Semiconductor Industry: A Key Contributor to U.S. Economic Growth, Semiconductor Industry Association, 2014.
2. National Nanotechnology Initiative – Strategic Plan, 2014.