
AC 2011-1023: INNOVATIVE GRADUATE PROGRAM IN NANOENGINEERING

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Dr. Ajit D. Kelkar is a Professor and Chairman of Nanoengineering department at Joint School of Nanoscience and Nanoengineering at North Carolina A&T State University. He also serves as an Associate Director for the Center for Advanced Materials and Smart Structures and is a Professor in the Department of Mechanical Engineering at North Carolina A&T State University, Greensboro. For the past twenty five years he has been working in the area of performance evaluation and modeling of polymeric composites and ceramic matrix composites. He has worked with several federal laboratories in the area of fatigue, impact and finite element modeling of woven composites including US Army, US Air force, NASA-Langley Research Center, National science Foundation, Office of Naval Research, and Oak Ridge National Laboratory. In addition he has collaborated with Rice University, Texas A&M University, Tuskegee University, Air Force Institute of Technology, University of Dayton, Florida State University, Prairie View A&M University, University of Delaware, Texas State University, University of Minnesota, University of California, and San Diego. His expertise are in the area of low cost fabrication and processing of woven composites using VARTM process, fatigue and impact testing of composites, analytical modeling of woven composites. Presently he is involved in the development of nano engineered multifunctional materials using XD CNTs and electro spun fiber materials. He is also involved in reengineering of several H-46 and H-47 helicopter components for NAVAIR using out of autoclave processing. In the past he has worked on the one step processing of Composite Armored Vehicle using low cost VARTM method in consortium with University of Delaware-CCM and UC San Diego. In the modeling area he is working on blast simulations for the Humvee vehicles subjected to various TNT blasts loadings. He has published over one hundred and fifty papers in these areas. In addition he has edited a book in the area of Nano Engineered materials. He is member of several professional societies including ASME, SAMPE, AIAA, ASM, and ASEE.

James G. Ryan, Joint School of Nanoscience and Nanoengineering

Dr. Ryan attended Rensselaer Polytechnic Institute in Troy, NY where he received his B.S., M.S. and Ph.D. degrees in Chemistry and an M.S. degree in Biomedical Engineering. Dr. Ryan is the Founding Dean of the Joint School of Nanoscience and Nanoengineering of North Carolina A&T State University and the University of North Carolina at Greensboro. His responsibilities include academic and administrative leadership of JSNN as well as the development of strategic partnerships with industry and government organizations. Dr. Ryan's research interests include thin film deposition, interconnect technology, semiconductor manufacturing technology and radiation hardened nanoelectronics.

Dr. Ryan joined JSNN after working at the College of Nanoscale Science and Engineering (CNSE) of the University at Albany as Associate Vice President of Technology and Professor of Nanoscience from 2005 to 2008. At CNSE, he managed the cleanrooms and numerous consortia involving CNSE and its industrial partners such as IBM, TEL, AMAT, ASML and others.

Dr. Ryan joined CNSE after a 25 year career with IBM. From 2003 to 2005, he was a Distinguished Engineer and Director of Advanced Materials and Process Technology Development and served as the site executive for IBM at Albany Nanotech. Prior to that assignment Dr. Ryan managed interconnect technology groups in research, development and manufacturing engineering areas at IBM. He is the author of over 100 publications and presentations, has 47 U.S. Patents and is the recipient of numerous awards including 17 IBM invention plateaus, an IBM Corporate Patent Portfolio award, an IBM Division Patent Portfolio Award, IBM Outstanding Technical Achievement Awards for Dual Damascene and for Copper technologies and the 1999 SRC Mahboob Khan Mentor Award.

INNOVATIVE GRADUATE PROGRAM IN NANOENGINEERING

Abstract:

Joint School of Nanoscience and Nanoengineering (JSNN) is establishing a new master's degree program in nanoengineering. The program will be highly interdisciplinary, drawing expertise and resources from various disciplines from two universities North Carolina A&T State University and University of North Carolina, Greensboro. Master of Science in Nanoengineering is designed for students with strong backgrounds in either engineering or science who seek additional specialized education and training to qualify them for positions in the field of nanoengineering or nanotechnology design, research and development, or manufacturing.

The proposed Master of Science in Nanoengineering degree program's objective is to produce graduates who are technically prepared and proficient with the principles and practices of engineering at the nanoscale to harness the unique and enabling aspects of nanoengineered materials, structures and their characteristics in engineering applications enabling them to directly enter industrial, government and private enterprises in the areas of nanoengineering design, research and development, manufacturing, or commercialization. This program will directly foster, through its formal research, education and internship programs, the kind of collaborative relationships emphasized in both institutions' strategic plans, across disciplines and with other institutions.

The proposed program will support many of the current and planned Research Clusters including: (1) Advanced Materials & Nanotechnology (new nanoengineered materials and manufacturing processes); (2) Energy and Environment; (3) Biotechnology and Biosciences (new materials & applications of nanoscience in biology, agriculture and medicine); and (4) Computational Science and Engineering (computational aspects of nanotechnology) that are key technology areas for the current and future scientific, engineering and technology needs of the nation and the world.

The rapidly spawning array of nanoengineered materials and techniques and their applications in research laboratories globally hold great promise for new nanoscale engineering systems and technologies. Commercial opportunities that could flow from the state's research enterprise in nanoengineering disciplines are particularly bright in the areas of advanced materials and manufacturing, aerospace, medicine and chemistry. In medicine, nanotechnology promises new drug delivery systems, implantable sensors, and new diagnostic tools offering real-time results. In materials, nanoscale particles, nano fibers and surface coatings offer to lower costs across a wide array of future generation materials for the defense and automotive applications.

Introduction:

The requirement for a skilled workforce with "Nano" skills has been articulated a number of times in the presentations and papers of Mihail Roco¹ of NSF who has projected that approximately 2 million nano-related jobs will be created by 2015 (40% of them in the US) and if typical multipliers are used the number of Nano-related jobs would be substantially more. This correlated with the predictions made by Lux Research (a well known contract research firm) that nanotechnology will contribute \$3.1 Trillion to the world's economy by 2015. We expect JSNN graduates to find positions in industrial, academic and government research labs in fields including pharmaceuticals, defense, materials and electronics companies.

The Joint School of Nanoscience and Nanoengineering (JSNN) currently offer two degree programs (a Professional M.S. in Nanoscience and a Ph.D. in Nanoscience). An M.S. degree program in Nanoengineering has recently been approved by the UNC System and that is the subject of the paper. There is only one other school in the United States that offers degrees in Nanoscience as well as degrees in Nanoengineering. It is the College of Nanoscale Science and Engineering (CNSE) of the University at Albany-SUNY. CNSE was established in 2004 and has produced a significant number of graduates who quickly find employment in the materials, equipment and semiconductor industries. One of the authors (Dr. Ryan) was a professor at CNSE for several years prior to becoming the Founding Dean of JSNN and is familiar with the success of CNSE's programs and students. Prior to his appointment at CNSE, Dr. Ryan worked for IBM and hired numerous CNSE graduates at salaries in the \$90K - \$100K range. Approximately 20 universities have developed "Nano" degree programs, mostly in the science or technology areas, but there are approximately four nanoengineering programs (including the one discussed in the paper). Although new academic programs, the graduates are working in some of the hottest technical areas. This fact combined with the co-location model used by both CNSE and JSNN where students and faculty work alongside industrial partners helps to promote job offers for the students. JSNN has developed relationships with both regional and international industrial partners and its relationships are expanding every day.

The JSNN conforms to the principles for joint programs stipulated by the UNC General administration. The way in which JSNN is academically set up is that all nanoscience students and nanoscience faculty are from UNCG and all nanoengineering students and faculty are NC A&T State University. Students and faculty can avail themselves of the resources at both universities and thereby promote the kind of internal collaborations that are needed to do research and teach a convergent field like "nano".

There has been tremendous student interest in JSNN's academic programs. JSNN received approval for its Ph.D. in Nanoscience in January of 2010. Although there was no time to advertise the program, we now had 17 Ph.D. students enrolled in August 2010. The M.S. in Nanoengineering is expected to follow the same track based on the number of calls, emails and verbal commitments to apply; we expect that we will be able to accept ~15 students into our Nanoengineering program. As an example of the interest in these graduate programs, CNSE received ~175 applications in 2008 and accepted a combined nanoscience & nanoengineering class of ~35 - 40 to make an entering class of around 30 students. Although JSNN does not yet

have as many applications, it is expected to rise substantially (JSNN nanoscience applications have seen a 2010 to 2011 increase of ~40%).

JSNN's research thrusts map into the businesses of North Carolina. Four areas of emphasis are now underway...Nanobiology, Nanometrology, Nanomaterials (with emphasis on nanocomposites) and Nanobioelectronics. After just 1 year of operation, JSNN now has a course catalog of 13 nanoscience courses, is in the process of creating 7 nanoengineering courses and has worked with the other schools and colleges of NC A&T SU and UNCG to offer graduate-level electives in Biology, Chemistry, Physics, Nutrition, Engineering, Technology and Business.

The program in nanoscience is intended to enable students with a variety of educational backgrounds to earn an advanced degree in nanoscience. Currently nanoscience students come from the disciplines of Biology, Chemistry, Physics, Math, Engineering, IT and Agriculture. The nanoengineering degree program requires the student to have an undergraduate engineering degree or be willing to take required undergraduate engineering courses to enable the student to learn the principles of engineering at the nanoscale.

Description of the Program:

Master of Science in Nanoengineering is designed for students with strong backgrounds in either engineering or science who seek additional specialized education and training to qualify them for positions in the field of nanoengineering or nanotechnology design, research and development, or manufacturing.

Educational objectives of the program:

The proposed Master of Science in Nanoengineering degree program's objective is to produce graduates who are technically prepared and proficient with the principles and practices of engineering at the nanoscale to harness the unique and enabling aspects of nanoengineered materials, structures and their characteristics in engineering applications enabling them to directly enter industrial, government and private enterprises in the areas of nanoengineering design, research and development, manufacturing, or commercialization.

The proposed program meshes well with both institutions educational and research thrusts in engineering, physical and biological sciences, and computational science and engineering. Most of the courses for this program will be drawn from courses currently offered by the two Universities. The proposed program also relates well to the doctoral program in Nanoengineering that is under development within the Joint School of Nanoscience and Nanoengineering (JSNN) as well as the professional Masters and Ph.D. program in Nanoscience within JSNN. The nanoengineering programs will focus on the principles and practices of engineering at nanoscale to harness the unique and enabling aspects of nanoscale, and nanoengineered materials, structures and their characteristics in engineering applications adding and complementing to the nanoscience programs with their focus on the fundamental study of materials and systems at nanoscale. The MS and Ph.D. nanoengineering programs ultimately complete the mission of the Joint School of Nanoscience and Nanoengineering.

Justification for the Program:

This program will directly foster, through its formal research, education and internship programs, the kind of collaborative relationships emphasized in both institutions' strategic plans, across disciplines and with other institutions. The proposed program will support many of the current and planned Research Clusters including: (1) Advanced Materials & Nanotechnology (new nanoengineered materials and manufacturing processes); (2) Energy and Environment; (3) Biotechnology and Biosciences (new materials & applications of nanoscience in biology, agriculture and medicine); and (4) Computational Science and Engineering (computational aspects of nanotechnology) that are key technology areas for the current and future scientific, engineering and technology needs of the nation and the world.

Student demand:

We anticipate the enrollment of 15 students in this joint nanoengineering program's first year. There is a huge demand for "nano-trained" engineers in the rapidly emerging nanotechnology revolution in the areas of nanoengineered materials, nanoelectronics, aerospace, biotechnology, medical devices, pharmaceutical, and defense and materials industries. It is expected that students will be interested in pursuing the degree as both part-time and full-time students to further educate and train in the different nanoengineering disciplines beyond their undergraduate engineering, science or technology degrees

Societal need:

The Joint School of Nanoscience and Nanoengineering's Master of Science in Nanoengineering program is designed to produce graduates with advanced training on the principles and practices of engineering at nanoscale to harness the unique and enabling aspects of nanoscale, and nanoengineered materials, structures and their characteristics in engineering applications so that they are prepared directly to enter industrial, government and private enterprises in the areas of nanoengineering design, research and development, commercialization or manufacturing. This is an important need in State of North Carolina In the recent times, the diverse array of disciplines of engineering, physical and biological sciences; computational science and engineering, and technology are converging to form interdisciplinary and emerging nanoengineering and nanotechnology enterprises.

The rapidly spawning array of nanoengineered materials and techniques and their applications in research laboratories globally hold great promise for new nanoscale engineering systems and technologies. The proposed graduate program will meet the required skilled workforce needed to attract these industries to the state of NC. "Research laboratories across North Carolina, particularly at its public and private universities, are "leading performers" that are required in quality nanotechnology research and development"² However, the State of NC lags other regions in the commercialization of these nanoengineering research efforts in terms of nanotechnology-based business start-ups and in employment opportunities for North Carolina's citizens that such start-ups would offer.

Commercial opportunities that could flow from the state's research enterprise in nanoengineering disciplines are particularly bright in the areas of advanced materials and manufacturing, aerospace, medicine and chemistry. In medicine, nanotechnology promises new drug delivery systems, implantable sensors, and new diagnostic tools offering real-time results. In materials, nanoscale particles, nano fibers and surface coatings offer to lower costs across a wide array of future generation materials for the defense and automotive applications.

To make the leap from the research laboratory to new products, and thus new jobs, requires an educated and well qualified workforce that comprehends simultaneously (a) the interdisciplinary principles of nanoengineering with the understanding of the unique and enabling properties at nanoscale and their associated nanoscale engineering and scientific principles (b) the implications that nanotechnology holds for not only revolutionizing the materials and products used in daily life but to see nanotechnology's promise for entirely new classes of products as well, (c) the skill set required for managing the nanoengineered material development, processing, design and nano-manufacturing procedures and (d) the ability to communicate an awareness and understanding about nanotechnology to the business and entrepreneurial community in the State of North Carolina. The central objective of the Master of Science in Nanoengineering degree program is to produce such trained nanoengineers for North Carolina businesses and manufacturing operations. Nanoengineering is an evolving field for the 21st century, a discipline that drives many engineering and science activities, the impact and associated technologies that will draw the industries of future growth as well as draw most creative minds. The educational programs of JSNN and the Masters program in nanoengineering will drive the associated knowledge based economy.

We believe this program will strengthen existing undergraduate and graduate programs in engineering, sciences, mathematics, computational science and engineering, and technology by offering an attractive alternative graduate program for the graduates of those programs in this exciting and evolving field of the future. As new industries and technologies evolve so are the needs for new educational programs. Historically, new educational programs have evolved to meet the related needs and opportunities; for example, computer engineering in 1970's, computer science in 1980, bioengineering in 1990s, computational science and engineering in 2000s and the nanoengineering programs of the 21st century. The committee does not believe the proposed program will stretch existing resources. Rather we feel it will further strengthen the interdisciplinary atmosphere on both campuses. The committee feels this program will appeal to a wide array of potential students and will not become low producing. Furthermore, the concomitant development of the doctoral program is expected to stimulate interest in nanoengineering and to further strengthen enrollment in the nanoengineering masters program.

Program Requirements and Curriculum:

1. Total hours required. - 30 credit hours (with thesis option and 33 credit hours with project option)
2. Proportion of courses open only to graduate students to be required in program (graduate programs only). – 50%
3. Other requirements – Internship or professional experience (6 credit hours)

Core Courses (12 credits): The student will take four courses that will introduce them to fundamental concepts, methods, and discoveries in different areas of Nanoengineering (These core courses are being created for the proposed Ph.D. in Nanoengineering). These courses include:

	Semester Hours		Semester Hours
Mathematical Methods in Nanoengineering	3	Fundamentals of Nanoengineering Physical Principles	3
Fundamentals of Nanoengineering Chemical-Biochemical Principles	3	Fundamentals of Nanomaterials	3

Disciplinary Foundation Courses (12 credits): These are courses that build on the undergraduate degree to ensure appropriate depth of knowledge in the student's discipline. Appropriate courses will be selected with a student's program advisor. These graduate level courses will come from offerings at both North Carolina A&T State University and the University of North Carolina at Greensboro.

1. Physics

Quantum Mechanics (E)

Physics of Atoms, Molecules and Nanosystems (E)

2. Chemistry

Introduction to Computational Chemistry (E)

Computational Methods in Protein Modeling and Drug Design (E)

3. Biology

Frontiers in Molecular Biology (E)

Cell and Molecular Biology (E)

4. Engineering

Introduction to Thin Film Technology (E)

Characterization Techniques for Nanomaterials (N)

Processing of Nanoengineered Materials for Alternative Energy Technologies (N)

Fundamentals of Nano and Micro Manufacturing (E)

Nanostructured Materials and Applications for Modern Chemical Processing Technologies (E)

Topics in Molecular Simulations (E)

Fundamentals of Nanoscience and Nanostructured Materials (E)

Introduction to Micro-Electro-Mechanical Systems (MEMS) (N)

Nanoelectronic Device Principles (N)

Environmental Impact of Engineering Systems (N)

Engineering in the 2020 Environment (N)

Construction Materials with Nano-Fillers (N)

Human-Computer Interaction for Wearable Nano Devices (N)

Computational Nanoscience and Nanoengineering (E)

Multi-Physics and Multi-Scale Modeling (E)

Computational Modeling Visualization (E)

Mechanics of Nanomaterials (N)

Processing, Characterization and Modeling in Nanoengineered Material Systems (N)

Additional courses in the areas of nanoscale transport phenomena, bio-nanomaterials, nanoelectronics, nanobiomaterials and sensors will be developed and offered.

5. Technology

Fundamentals of Nano and Micro Manufacturing (E)

(E = existing course; N = new course)

6 credit hours of thesis or 3 credit hours of Project (in case of project option, student will be required to take 30 credit hours of course work – 12 credit hours of core courses, 18 credit hours of disciplinary foundation courses).

References:

1. A Roadmap for Nanotechnology in North Carolina's 21st Century Economy. NC Board of Science & Technology, April 2006.
2. Mihail C. Roco and William Sims Bainbridge, "Societal implications of nanoscience and nanotechnology", Springer 2001, ISBN 079237178X, 9780792371786