Title of Program/Certificate, etc: Graduate Certificate in Nanotechnology and Nanoscience

Level (Masters/Ph.D.): Graduate Certificate

Please list the contact person for this new certificate, concentration, track or program for incoming students:

Peter A. Becker, Associate Dean for Graduate Studies, School of Computational Sciences

Approval from other units:

Please list those units outside of your own who may be affected by these. Each of these units must approve this program prior to its being submitted to the Graduate Council for approval.

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<tr>
<th>Unit: IT&amp;E</th>
<th>Head of Unit’s Signature:</th>
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<td>Unit: CAS: Chemistry</td>
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Submitted by: _____________________________ Email: ____________

Graduate Council approval: _____________________________ Date: ____________

Graduate Council representative: _____________________________ Date: ____________

Provost Office representative: _____________________________ Date: ____________
Graduate Certificate in Nanotechnology and Nanoscience

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1. Executive Summary

Nanotechnology and Nanoscience are of great importance in a wide range of industries and are fundamental for the success of the region and the nation in the 21st century. Hence it is imperative that these fields be incorporated into the education of the next generation of applied scientists and engineers. The proposed Graduate Certificate in Nanotechnology and Nanoscience addresses the need for qualified professionals in these critical areas.

Graduate Certificates are becoming increasingly common in universities around the country, because they serve the needs of the busy modern professional. Such persons rarely have the luxury of time to undertake a full course of study leading to advanced degrees such as the M.S. or Ph.D. Indeed, in many cases they do not have the need for such a degree, as they may frequently already have advanced degrees. These prospective students are often attracted to a certificate program based on a focused set of courses that presents a complete, well-rounded, practical, and up-to-date view of the key information in their professional area.

The certificate is composed of five courses (16 credit hours) focusing on two key areas of knowledge, namely (1) nanomaterials and nanostructures and their relation to bulk materials, and (2) methods for characterization and production of nanomaterials. The proposed program will be attractive to students and professionals who wish to benefit from the employment boom in the nanoscience fields. Graduates will be well prepared to fill the demand for personnel with nanoscience training who can serve as process controllers in area fabrication facilities, and/or participate as members of interdisciplinary science teams.

We believe that the proposed Graduate Certificate in Nanotechnology and Nanoscience will prove very attractive to students and employers in the Northern Virginia-Washington, D.C. geographical area as explained in detail below.

2. Description of Proposed Graduate Certificate

2.1 Mission and Objectives

The general area of Nanoscience and Nanotechnology is one of the most rapidly developing scientific disciplines, reflecting the fundamental need for a vastly improved human understanding of the complex, interconnected processes in the nanoscale regime. In the past three years, this effort has greatly benefited from an enormous influx of resources dedicated to research, development, education, and implementation provided mainly by government agencies. This influx of funds is stimulating the private sector to invest in new nanotechnologies and also to support interdisciplinary sciences that emphasize nanoscience in general. The Nanotechnology Initiative, signed in 2001, is the governmental mandate that has driven all agencies in the U.S. to invest heavily in Nanoscience and Nanotechnology. State governments across the nation have also continued to invest millions of dollars in this field. In the private sector, large corporations such as IBM, Motorola, Hewlett Packard, Lockheed Martin, and many others, are focusing R&D heavily on applications of nanotechnology.
The primary mission of the proposed Graduate Certificate in Nanotechnology and Nanoscience is to equip students to meet the needs of society by working in the rapidly developing area of nanotechnology. The certificate will enable students to acquire knowledge on a broad range of instrumentation, modeling, analysis, and production methods that all facilitate the solution of practical nanotechnology-related problems in the workplace. In particular, the certificate will highlight the effect of size on physical and engineering properties, and also on the design of various devices/systems and special-purpose materials. Students finishing the certificate proposed here may choose to pursue one of the engineering or science related graduate degrees. Courses completed for the certificate will be completely counted toward any of these graduate degrees, consistent with their limitations on electives and level of the courses.

Graduates from the proposed certificate program will have a working understanding of the different methodologies utilized in the characterization of nanomaterials, and they will also have the skills to address practical problems related to their manufacturing. More broadly, through completion of the proposed certificate, graduates will obtain the fundamental interdisciplinary knowledge critical for understanding nanostructures and the functioning of nanodevices. These skills will make them qualified to participate as members of interdisciplinary nanoscience teams. The experiences gained in the proposed program will be of immediate relevance for the burgeoning high-technology workforce in the Northern VA region by producing graduates who have the skills many area employers are seeking. For example, one beneficiary will be Luna Technologies, in Danville, VA, which has so far been unable to fulfill their need for personnel to fill technical positions associated with the fabrication of devices based on nanotubes. Graduates from the proposed program will be well suited for this type of position in local private industry.

2.2 Administrative Structure

The certificate will be administered by the Fluids and Materials Program within SCS and will also support the needs of the ECE Department in IT&E. Currently, faculty members in the Mason Nanotechnology Forum oversee all Mason research associated with the proposed certificate. The Certificate Coordinator, Professor Estela Blaisten-Barojas, will direct the administration of the proposed certificate. The Coordinator will supervise the admission of students into the program, monitor student progress, advise students, promote the certificate, and coordinate and schedule course offerings. The mechanics of the admission process (i.e., application processing, student record control, etc.) will be handled by the SCS Student Services Office in close consultation with the ECE Department in IT&E. The Certificate Coordinator will work closely with SCS and ECE admissions staff and also with the Deans for Graduate Studies of both Schools on general administrative issues and processes.

2.3 Admission Requirements

Admissions requirements for the proposed Graduate Certificate in Nanotechnology and Nanoscience include:

- Bachelor’s degree in any branch of engineering, physics, chemistry, or materials science.
- Undergraduate GPA of 3.00 or higher. Exceptions are reviewed on an individual basis.
• Completed GMU graduate application, professional resume, and official transcripts from each institution attended.

• The TOEFL exam is required for all non-native speakers of English (this requirement is waived if the applicant holds a degree from a US school).

Students may not pursue this certificate concurrent with any other SCS graduate degree program or certificate program because this certificate will charge students at a differential (premium) tuition rate. However, students enrolled in academic programs outside SCS may enroll in this certificate program concurrently.

Students may not transfer any coursework into the proposed certificate program from previous graduate study except if prior agreement from the Certificate Coordinator has been granted.

2.4 Curriculum Requirements

Completion of 15 credit hours including:

• CORE: Two 3-credit core courses to give a common background in nanotechnology. The two courses are selected from a list of three possible courses as indicated below.

• ELECTIVES: Three 3-credit elective courses chosen from the list of four courses specified below, with at least one at the 600-level.

The certificate must be completed in three years maximum.

Core Courses:

NANO 500 Introduction to Nanomaterials and Interactions (3 credits)
NANO 510 Strategies for Nanocharacterization (3 credits)
NANO 520 Survey of Nanostructures (3 credits)

Elective Courses:

NANO 530 Nanofabrication (3 credits)
NANO 540 Public Policy and Legal Issues in Nanotechnology (3 credits)
NANO 610 Nanoelectronics (3 credits)
NANO 620 Computational Modeling in Nanoscience (3 credits)
2.5 Relationship to other GMU Programs

No comparable certificate program is currently being offered at GMU. The proposed certificate is broad and application-oriented in the sense that it focuses on the practical techniques and methods used to approach real-world situations in involving nanotechnology and nanoscience problems.

At GMU, several degree programs provide formal training and course work related to physical sciences and electrical engineering, but no certificate program is designed specifically to meet the mission and objectives of the proposed certificate.

3. Justification for Proposed Graduate Certificate

3.1 Student Demand

Our research on student demand for this certificate is based upon our first-hand knowledge of the nanotechnology industry and the related workforce in the Washington, D.C. metropolitan area, and also on the nation-wide development trends involving interdisciplinary nanotechnology and nanoscience training, which will be addressed in more detailed in section 3.3. The Washington, D.C. region (including counties in Virginia and Maryland) probably has the highest concentration in the nation of science and engineering professionals and the highest demand in the nation for such professionals in both the government and private sectors. The large number of employees at these organizations will provide a steady supply of students for enrollment in the proposed certificate program.

Below is a partial list of Federal government agencies and establishments with a large presence in the Washington, D.C. area either in terms of producing research in nanotechnology or requiring an increasing number of trained scientists and technicians:

NIST
NASA Goddard Space Flight Center
Naval Research Laboratory
Patent Office
Institute for Defense Analyses
Environmental Protection Agency
NIH

These government agencies currently need qualified professionals and scientists. Some of their employees have been in the workforce for a significant period of time, and may greatly benefit from the re-training possibilities offered by the proposed certificate. As the use of nanotechnology in military and civilian applications continues to grow, we believe that students who are not currently working in this field may wish to increase their chances of being hired by these agencies by completing our proposed certificate.

In the private sector, several companies that are major players in the nanotechnology arena are located in the GMU region. These include many large defense, IT, and environmental consulting companies. Below is a partial listing of these corporations:
The companies listed above, and many others, will likely send their employees to GMU to pursue advanced training in the science and technology/applications areas of nanotechnology and nanoscience in order to support the growth of their businesses. The existence of this certificate will allow them to hire graduates with engineering and/or physical sciences backgrounds, and then send them to GMU for advanced nanotechnology training.

We have personal contacts with some of these companies via our faculty and alumni, and it is quite clear that these corporations are eager to take advantage of such a locally provided certificate program to enhance the skills of their current employees, and also to equip qualified science professionals and engineers for subsequent employment by their companies.

### 3.2 Employer Demand for Graduates

The students interested in the certificate may have backgrounds in several physical sciences, such as solid state physics, materials science, chemical synthesis, or in a variety of engineering areas, such as electronic engineering, mechanical engineering, device engineering. Some others may have a background in bio-medical science and law. It is likely that a number of them may already have some formal training in nanotechnology. We expect that our graduates from this certificate will be classified as Nanoscience-Nanotechnology scientists or professionals in the materials and device areas, since as yet there is no formal category for nanotechnology scientists in the labor market. However, we expect that our graduates will have an edge over other engineers and material scientists because they are also equipped with characterization, theoretical, and modeling expertise. Therefore, in our assessment of employment demand, we focus on the categories of device scientists and materials professionals.

According to the White House initiatives, President Bush signed the Nanotechnology Research Development Act on December 2003, “which authorizes funding for nanotechnology research and development (R&D) over four years, starting in FY 2005. This legislation puts into law programs and activities supported by the National Nanotechnology Initiative (NNI), one of the President's highest multi-agency R&D priorities.” Quoted from the vice-president’s recent address in October 2004, “Our administration has doubled federal funding for nanotechnology research and development.” The IEEE has also broadly endorsed these new technologies (http://www.ieeeusa.org/policy/positions/nanotechnology.html). The Bureau of Labor Statistics still has no data in this nascent area of science and technology. However, the agency indicates that in the area of mechanical engineers, nanotechnology is likely to be an area of increased hiring in the next six years (http://www.bls.gov/oco/ocos033.htm). Furthermore, according to publications by the
American Physical Society (http://www.aps.org/apsnews/current/110408.cfm), across the country there are several new multimillion research and characterization centers that are uniquely dedicated to the findings of applications to various fields such as medical devices and cures.

The proposal for this certification was presented in various professional communities, i.e., the Northern Virginia Technology Council Nanotechnology Committee, The Nanotechnology Initiative of Virginia, The Center of Innovative Technology, The Atlantic Nano-Forum, The Joint Commission on Technology and Science (JCOTS), and the Technical Office of the Fairfax County Government. The response was overwhelmingly supportive.

In short, we are very optimistic about the job prospects for graduates from the proposed certificate program, given the development trends in the labor market for Nanoscience researchers and professionals with Nanotechnology expertise in the region and the nation.

3.3 Comparison with Other Programs in the Region and the Commonwealth

While the demand for nanotechnology professionals in this region and nationwide is relatively high and on the rise, most professionals receive education and training through formal degree programs, which require significant commitment of one’s time and resources. Little is available in post-graduate training beyond the traditional degree programs. The proposed graduate certificate therefore serves a special niche in meeting the needs of nanotechnology professionals in the Northern VA area, and potentially for the nation.

We have performed a survey on the Internet to identify programs in the region and the nation similar to the one proposed here. We found no existing programs in the Washington, D.C. area. Nationally, we found that Duke University, Stanford University, Leigh University, and the University of Pennsylvania are offering certificate programs similar to the one proposed here.

3.4 Projected Enrollment

We expect that enrollment in the proposed certificate program will initially be small as it is intended for Spring 2005 origination. However, the number of students enrolled in the program is likely to increase quickly as news about the availability of the certificate spreads throughout the local corporate high-tech community. Below are some projected figures for the number of students enrolled in the certificate program:

<table>
<thead>
<tr>
<th>Year</th>
<th>Spring</th>
<th>Fall 2005</th>
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<td>10</td>
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In the long run, we would like to keep the enrollment of the certificate between 20 and 25. We expect those enrolling in the certificate will be primarily part-time students, and therefore they will take only one to two courses per semester. Consequently, on average, a student will complete the certificate program in about two years. We expect to offer one course during each summer, and two courses during each of the regular academic semesters.
3.5 Differential Tuition Rate

We propose that the graduate certificate will charge students at a differential (premium) tuition rate, with an additional $100 per credit hour added to the standard GMU graduate tuition for students who enroll in this certificate program (regardless of in-state or out-of-state status). The additional $100 per credit hour (with $75 returned to SCS) will be used to maintain and improve the computational and laboratory infrastructures necessary for supporting the proposed program. Based on standard GMU tuition for the AY 2004-2005, in-state graduate students in the certificate program will therefore pay $345/credit hour and out-state students will pay $723/credit hour. We note that when our tuition is compared with private institutions in the area, these suggested rates are quite competitive. For example, graduate students at George Washington University (GWU) are charged $810 per credit hour, and at Georgetown University, the rate is $993 per credit hour.

As stated above, the rationale for the differential tuition is that the portion returned to SCS will help to fund the continued improvement in the underlying academic infrastructure required to support the certificate program.

4. Resource Needs

4.1 Faculty

The Mason Nanotechnology Forum, the Fluids and Materials Program in the School of Computational Sciences, and the Electrical and Computer Engineering Department in IT&E have a faculty body that would like to be involved in this certificate instruction. The primary faculty members supporting the proposed certificate and their respective courses are:

Estela Blaisten (NANO 620)
Christopher Hill (NANO 540)
Kiki Ikossi (NANO 530)
Dimitris Ioannou (NANO 610)
Maria Merino (NANO 520)
John Schreifeld (NANO 510)
Boris Veytsman (NANO 500)

Several other faculty members have also expressed interest in participating in the proposed certificate program. Professor Estela Blaisten-Barojas will serve as the Coordinator of the certificate program.

We expect that existing funds will be reallocated to support three adjuncts per calendar year.

4.2 Equipment and Laboratory Environment

The microelectronics laboratory and the surface characterization laboratories would be accessible to the students (a laboratory fee may be applicable). We also have an offer from FM Technologies in Reston to conduct two classes per semester on their grounds using their laboratory equipment. Additionally, a partnership with the Institute for Nanotechnology and Nanoscience of the Naval
Research Laboratory is currently being sought to facilitate the loan of certain laboratory equipment during the semester as needed. An equivalent partnership is also in discussion with the Detector System Branch of NASA/Goddard Space Flight Center.
Appendix I: Catalog Descriptions of Proposed Courses

NANO 500 Introduction to Nanomaterials and Interactions (3:3:0). Prerequisites: admission into the Graduate Certificate in Nanotechnology and Nanoscience. Introduction to nanotechnology. Discussion of the Feynman challenge and its relation to modern science. Atoms and states; a review of quantum mechanics; energy levels; excitations. Includes light absorption and luminescence; covalent and hydrogen bonds in nanostructures and polymers; conformations of polymers; random walks; biological nanostructures and bio-inspired self-assembly. Discussion covers collective effects in nanostructures; one-dimensional lattices; delocalization; electron spectrum; proton excitations. Emphasis on two-dimensional and three-dimensional lattices. Applications to nanostructures of charges, currents, diamagnetics, paramagnetics and ferromagnetics.

NANO 510 Strategies for Nanocharacterization (3:3:0). Prerequisites: NANO 500 and admission into the Graduate Certificate in Nanotechnology and Nanoscience. Introduces various nanocharacterization techniques, with a discussion of which techniques are most useful in various applications. Spatial resolution and detection methods in several-electron microscopy techniques (SEM, TEM, LEED). Ion-beam techniques, surface techniques and their limitations. Mass spectrometry (MALDI, cluster desorption), as well as STM and AFM techniques. IR and Multiwavelength spectroscopies. Includes gates and bridges; chemical thermodynamics; kinetics; and solid-state reactions. Various nanomaterials are treated such as metals, ionic crystals, and semiconductors. Solid-vapor phase thermal sublimation. Piezoelectric and pyroelectric mechanisms. Polar surfaces in nanodevices, and catalytic reactions.


NANO 530 Nanofabrication (3:3:0). Prerequisites: NANO 500 and 510, and admission into the Graduate Certificate in Nanotechnology and Nanoscience. Covers pulsed laser deposition; molecular beam epitaxy; controlled vapor deposition; reactive sputtering; doping and implant isolation. Also includes discussion of plasma etching; ohmic and Schottky electrical contacts. Micro- and nanoelectromechanical systems. Covers motion of a nanofilament in electrical and magnetic fields.

NANO 540 Public Policy and Legal Issues in Nanotechnology (3:3:0). Prerequisites: NANO 500 and admission into the Graduate Certificate in Nanotechnology and Nanoscience. Discusses competitive position of the United States and other countries in nanoscience and nanotechnology. Business strategies. Environmental and public health aspects of nanotechnology applications. Legal, economic, social and political controls over nanoscience research and nanotechnologies.
**NANO 610 Nanoelectronics (3:3:0).** Prerequisites: NANO 500, 510, 520, and 530, and admission into the Graduate Certificate in Nanotechnology and Nanoscience. Introduces basic elements of nanoelectronic structures, including quantum layers, quantum wires and quantum dots. Covers subband structure; transport in quantum layers; behavior in the presence of magnetic fields; Coulomb blockades; CMOS nanodevices and nanoelectronics; and SOI multi-gate device physics and modeling.

**NANO 620 Computational Modeling in Nanoscience (3:3:0).** Prerequisites: NANO 500, 510, and 520, and admission into the Graduate Certificate in Nanotechnology and Nanoscience. Introduction to simulation methods used in nanoscience. Covers computational approaches to modeling molecular and condensed matter at the nanoscale level, including interatomic and molecular potentials; molecular mechanics; molecular dynamics; monte carlo averaging; ensemble distributions; numerical sampling; thermodynamic functions; dynamic structure; and an introduction to cellular automata.