The University of North Carolina at Charlotte

Ph.D. in
Nanoscale Science

Request for Authorization to Plan

Appendix B

The University of North Carolina
Request for Authorization to Plan a New Doctoral or First Professional Degree Program

THE PURPOSE OF ACADEMIC PROGRAM PLANNING: Planning a new academic degree program provides an opportunity for an institution to make the case for need and demand and for its ability to offer a quality program. Authorization to plan, and the planning activity to follow, do not guarantee that authorization to establish will be granted. Requests (5 copies) may be submitted annually, by September 15 of each year.

Date April 28, 2005

Constituent Institution: University of North Carolina at Charlotte

CIP Discipline Specialty Title: Physical Sciences, Other

CIP Discipline Specialty Number: 40.9999 Level: D ☒ 1st Prof. ☐

Exact Title of the Proposed Degree Nanoscale Science

Exact Degree Abbreviation (e.g. Ph.D.,Ed.D.): Ph.D.

Does the proposed program constitute a substantive change as defined by SACS? Yes ☐ No ☒

a) Is it at a more advanced level than those previously authorized? Yes ☐ No ☒

b) Is the proposed program in a new discipline division? Yes ☐ No ☒

Approximate date for submitting the Request to Establish proposal (must be within two years of date of authorization to plan): April 30, 2006

Proposed date to establish degree: *month* August *year* 2007 (Date should allow at least three months for review of the request to establish, once submitted.)

Table of Contents

1. Describe the proposed new degree program.

a) a brief description of the program and a statement of educational objectives

The University of North Carolina at Charlotte requests authorization to plan a Ph.D. program in Nanoscale Science. The program will involve five departments (Chemistry, Physics and Optical Science, Mechanical Engineering and Engineering Science, Electrical and Computer Engineering, and Biology), the Center for Optoelectronics and Optical Communications, and the Center for Precision Metrology. The program will be administered through the Department of Chemistry. Considerable strengths in the above departments are evident to sustain a strong interdisciplinary program in this rapidly emerging field that is vital to the economic prosperity of North Carolina and the nation. Faculty members from the above science and engineering departments who are engaged in research in nanoscale science and engineering will serve as doctoral program faculty. The program connects with existing programs at the institution and is consistent with relevant national priorities. The focus of the Ph.D. program in Nanoscale Science is to educate and train the needed scientists who will broaden our understanding of phenomena at nanometer length scales and applications of nanoscale science, and who will develop the knowledge required to train future generations of workers in the field. The research accomplished by the graduates of this new program will add to the body of scientific knowledge needed for our economy to stay competitive on the national and world stages.

Nanoscale science is a field of scientific investigation that addresses the development, manipulation and use of materials and devices on the scale of roughly 1-100 nanometers in length, as well as the study of phenomena that occur at this size scale (one nanometer equals one billionth of a meter). This size range encompasses the smallest man-made and naturally derived devices known. One can gain a perspective of the nanometer scale by considering the sizes of some familiar objects. For example, a sheet of paper is roughly 100,000 nanometers thick, critical dimensions in integrated circuits are less than 10 nanometers, while large polymers and proteins are just a couple of nanometers in size.[1]

The field of nanoscale science was conceptually born out of Richard Feynman's famous 1959 lecture, "There's Plenty of Room at the Bottom."[2] In this presentation Feynman pondered radical notions such as writing an entire set of the Encyclopedia Britannica on the head of a pin through the manipulation of individual atoms. At that time, the tools required to fabricate materials and devices at the atomic/molecular scale and to measure their properties were not available. The advent of scanning probe microscopes and their ability to measure and manipulate matter at the nanoscale, microelectronic and optoelectronic device manufacturing technology, as well as developments in macro-scale molecular modeling and powerful computational capability, are all enabling the ideas of exploiting the benefits of nanoscale manufacturing to be realized. These tools allow scientists to observe objects at the nanoscale, to discover new phenomena at these small dimensions systematically rather than by accident, and to synthesize and manipulate nanoscopic particles by rational design rather than serendipity.

Nanoscale science offers many challenges and opportunities for scientific understanding and potential technological advances.[3] It is predicted that nanoscale science will change the nature of almost every human-made product this century. This field has great potential applications in materials, medicine, electronics, optics, data storage, advanced manufacturing, environment, energy, and national security. Some specific applications include: lightweight new materials with greatly improved strength and wear characteristics; ultradense computer memory; better drug design and better drug and gene delivery; sensing applications for agricultural, biological, chemical and homeland security applications; improved catalysts for the chemical and automotive industries; new materials to improve fuel economy and carbon dioxide emissions; and improved batteries and energy efficient processes for energy technologies. Nanoscale materials already find use in numerous pharmaceutical, catalytic, electronic, magnetic, optoelectronic, biomedical, cosmetic and energy applications. Specific applications reporting the highest revenues include sunscreens, automotive catalyst supports, chemical-mechanical polishing, magnetic recording tapes, biolabeling, electroconductive coatings, and optical fibers. Other applications include dental-bonding agents, protective and glare-reducing coatings for eyeglasses and cars, stain-free clothing and mattresses, paints and coatings to protect against corrosion, scratches and radiation, burn and wound dressings, and automobile catalytic converters.

There is a growing sense of urgency to scale up nanoscale science research efforts in the United States and worldwide. The establishment of the National Nanotechnology Initiative (NNI) articulates the deep commitment of the U.S. to research and development in nanoscale science and engineering.[4] The NNI "provides a multi-agency framework to ensure U.S. leadership in nanotechnology that will be essential to improved human health, economic well being and national security. The NNI invests in fundamental research for further understanding of nanoscale phenomena and facilitates technology transfer."[4] The goals of the NNI are as follows:

- Maintain a world-class research and development program aimed at realizing the full potential of nanotechnology

- Facilitate transfer of new technologies into products for economic growth, jobs, and other public benefit

- Develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology

- Support responsible development of nanotechnology

Federal investment in nanoscale science R&D increased from $116 million in FY 1997 to a over $1 billion for FY 2005 (nearly a 10-fold increase).[4] *The 21st Century Nanotechnology Research and Development Act*, signed into law in December, 2003, makes nanotechnology the highest priority funded science and technology effort since the space race. At least 35 other countries have initiated nanoscale science activities at the national level.

Funding for research in nanoscale science and engineering is also prevalent in the industrial sector. A survey of R&D expenditures of U.S. industries in 2002 indicated that 2418 companies with R&D in the technology areas of biotechnology, materials synthesis, and software development *attributed 50% or more of their R&D expenditures to nanotechnology*.[5] The funding level in industry for R&D in nanoscale science roughly matches that of the federal level.[6]

The National Science Foundation estimates that nanotechnology will be a $1 trillion global industry by 2010-2015.[7] This will require about 2 million workers in the field of nanoscale science and engineering,[7] of which 0.8-0.9 million will be in the United States.[8] There is a pressing need to train workers who will contribute to this vital area by conducting scientific research, working in industry, and educating students in universities, colleges, community colleges, and elementary and secondary schools. M.C. Roco, Senior Advisor for Nanotechnology at the National Science Foundation, articulates **the great need for education in nanoscale science**:

> "The key goals of nanotechnology are advances in molecular medicine, increased working productivity, extension of the limits of sustainable development and increased human potential. And yet, one of the "grand challenges" for nanotechnology is education, which is looming as a bottleneck for the development of the field, and particularly for its implementation."[8]

The importance of Nanoscale Science to North Carolina. Nanoscale Science will be important to the economic development of North Carolina. The North Carolina Economic Development Board's 2004 strategic plan charged the NC Board of Science and Technology with coordinating an emerging technologies initiative in the following action item:

> "Implement an initiative to promote economic growth in North Carolina through the identification and development of emerging technologies. For example, nanotechnology-the science of the very small-will fundamentally transform science, technology, and society, from microscopic computer chips to cancer-fighting vaccines. As such, it holds tremendous potential for North Carolina and the nation. Nanotechnology will be the basis of manufacturing technology in the future. Developing a coordinated response to the challenges and opportunities presented by emerging technologies will greatly expand the opportunity for all North Carolinians to obtain and retain challenging and economically rewarding employment. An initiative to coordinate efforts within the state will link its strengths to grow new industries, educate our workforce, capture federal funding, and maintain North Carolina's technology leadership while revitalizing its traditional industries around these new technologies."[9]

In response to this call, the NC Board of Science and Technology established the North Carolina Nanotechnology Initiative Planning Committee to make recommendations on how to increase North Carolina's stature in the nanotechnology arena. Currently, North Carolina ranks about 20th in nanotechnology in the nation. The establishment of a Ph.D. program in Nanoscale Science at UNC Charlotte will help to bring employment opportunities of all levels to the greater Charlotte and surrounding areas, and will provide nanoscale science and nanotechnology training for workers that will be needed throughout North Carolina.

The educational objectives of the proposed Ph.D. program in Nanoscale Science are as follows:

- Provide students with knowledge and educational opportunities in pure and applied nanoscale science, culminating in an interdisciplinary, research-based Ph.D. degree in Nanoscale Science.

- Produce a supply of doctoral level scientists who will lead in (1) improving our understanding of the nanoscale regime and its many applications; (2) developing nanotechnology industrial initiatives in North Carolina; and (3) providing educational opportunities to train the workforce needed to sustain the growth of nanoscale science in North Carolina and the U.S.

- Develop and train independent scientists and scholars who possess the critical thinking, methodological, and communication skills required to advance and disseminate knowledge of fundamental and applied nanoscale science

- Enhance the educational experience in science and engineering for all graduate and undergraduate students at UNC Charlotte.

Based on the combined strengths of faculty members in Chemistry, Physics and Optical Science, Mechanical Engineering and Engineering Science, Electrical and Computer Engineering, and Biology, the proposed program will focus on the following areas of research:

Theoretical Aspects of Nanoscale science

- Development of methods to model, synthesize, characterize, simulate and evaluate complex materials including photonic crystals, photonic devices and other complex materials such as high temperature superconductors and plasmonic devices.

- Modeling and predicting quantum effects that become significant in nanoscale materials, and to utilize these effects in new materials and applications (including quantum dots, quantum wires, nanotubes, and photon confined materials).

- Identification, understanding, and utilization of the concepts applicable to the controlled assembly of self-organizing nanomaterials, including polymers, dendrimers, nanotube-based materials, nanocatalysts at surfaces (including electrode surfaces), and assemblies of biopolymers.

Biomolecular Nanotechnology

- Design, fabrication, and optimization of biomaterials and devices for tissue growth and repair.

- Elucidating the structures of complex biomolecules and understanding interactions between biomolecules.

Building Nanoscale Materials

- Development and utilization of nanoscale lithographic processes.

- Synthesis of materials at the nanoscale, including: polymers, dendrimers, supramolecular complexes, quantum dots, quantum wells, carbon nanotubes, molecular material hybrids, high energy / high density compounds, and nanoporous materials.

- Development of synthetic methodology and mechanistic studies.

- Fabrication of nanopatterned surfaces and nanostructured metal composites for chemical and biological sensing.

Instrumental Methods for Nanotechnology

- Development of instrumentation and procedures for the machining, manipulation, and replication of materials with nanometer precision.

- Intertwining material development with cutting-edge nanoscale analytical techniques, including surface probe techniques with atomic resolution and novel metrology methods. There is a significant relationship between form and function at the nanoscale. Rapid, high-precision analytical information will stimulate rational material design.

b) the relationship of the proposed new program to the institutional mission and how the program fits into the institution's strategic plan

The proposed Ph.D. program in Nanoscale Science is connected specifically to a range of University goals including: (a) to provide services that impact positively the many challenges facing the region, state, and nation; (b) to train graduate students who possess interdisciplinary skills and capacities that can be applied to a variety of situations and professions in an ever-changing world; (c) to increase the number of Ph.D. programs in high demand fields; and (d) to reach doctoral/research-extensive status by the year 2010. Increased demand for graduate-level offerings is intrinsic to these goals and meeting that demand will have multiple benefits for UNC Charlotte, North Carolina, and the region.

The Campus Academic Plan serves as the guiding force for decisions concerning the number and direction of academic programs, the work of faculty and support staffs, and the allocation of resources. It is designed to capture the most important initiatives and priorities of the constituent units and programs of the University and to place them within the context of a set of overarching goals and values for the campus as a whole. Since the *Campus Academic Plan for 1998-2003*, each University initiative is scrutinized in relation to one or more of the seven themes for campus development that serve as guideposts for the creation of new degree programs and curricula at both the undergraduate and graduate levels. With a broad institutional commitment to liberal education as the foundation for constructive citizenship, professional practice, and lifelong learning, UNC Charlotte is prepared to focus interdisciplinary resources to address seven broad areas of concern to the Charlotte region. These include: 1) Liberal Education; 2) Business and Finance; 3) Urban and Regional Development; 4) Children, Families, and Schools; 5) Health Care and Health Policy; 6) International Understanding and Involvement; and 7) **Applied Sciences and Technologies**.

The *2004-2009 Academic Plan of UNC Charlotte* documents UNC Charlotte's interest in the development of a Ph.D. in Nanoscale Science, in support of the theme of Applied Sciences and Technologies:

> "The new degree program is proposed in response to the accelerating growth in nanoscale science and nanotechnology at the University and, indeed, around the world. This interdisciplinary program would be based in the Department of Chemistry. The proposed program will involve the Departments of Mechanical Engineering (Metrology), Electrical and Computer Engineering, Biology, Mathematics and Physics and Optical Science and will build upon existing and future collaborative educational and research efforts with existing graduate and undergraduate programs within these units."

During 2003-2004 and 2004-2005 academic years, the planning committee for the Ph.D. program in Nanoscale Science, composed of faculty members, nominated by the department chairs of the participating departments, investigated the need for the program, explored graduate programs in nanoscale science at other institutions, addressed the scope of the proposed program, and outlined the curriculum. The department chairs agreed to support the proposed program.

c) the relationship of the proposed new program to other existing programs at the institution

The proposed Ph.D. program in Nanoscale Science will weave continuity between the pursuits of the baccalaureate and master's programs in Chemistry with those of the Ph.D. programs in Optical Science and Engineering, Mechanical Engineering, Electrical Engineering, and Biology. Graduate students in the Nanoscale Science Ph.D. program will interact with students and faculty members of other Ph.D. programs at UNC Charlotte by enrolling in courses offered by the other graduate programs on campus, attending and presenting seminars on nanoscale science, and by working together on research projects. Many of the faculty members who will participate in the Nanoscale Science Ph.D. program are also members of the faculty of the Ph.D. programs listed above. Numerous ongoing interdisciplinary collaborations among these faculty members are already resulting in externally funded projects and peer reviewed publications. The Ph.D. program in Nanoscale Science will enhance these activities by offering courses that will better prepare students to engage in research in nanoscale science, and by providing a more focused forum for scientists at UNC Charlotte to conduct research in nanoscale science.

The study of nanoscale science and engineering is an active research area within the Charlotte Research Institute's Center for Precision Metrology and Center for Optoelectronics and Optical Communications. Research projects of faculty in the Ph.D. program in Nanoscale Science will complement and enhance the research activities of these centers.

d) special features or conditions that make the institution a desirable, unique, or appropriate place to initiate such a degree program.

Over 30 faculty members from the departments of Chemistry, Electrical and Computer Engineering, Mechanical Engineering and Engineering Science, Physics and Optical Science, and Biology are willing to serve as program faculty by teaching in the curriculum, mentoring students in research, and conducting collaborative research. Brief profiles of the participating faculty are provided in the appendix. Faculty in the participating departments already conduct collaborative, funded, cross-disciplinary research in nanoscale science and have published the findings of their work in peer-reviewed journals.

UNC Charlotte's Center for Precision Metrology is a partner of the NSF-funded Center for Scalable and Integrated NAnoManufacturing (SINAM) in conjunction with UCLA, UC Berkeley, Stanford University, UC San Diego, and HP Labs.

UNC Charlotte already offers two graduate level courses in nanoscale science, one based in the Department of Mechanical Engineering and Engineering Science, the other based in the Department of Chemistry (but taught as an interdisciplinary course). Numerous graduate level courses that are already offered on campus through the Ph.D. programs in Mechanical Engineering, Electrical Engineering, Biology, and Physics and Optical Science will benefit the proposed Ph.D. program in Nanoscale Science and will be crosslisted in that program.

2. List all other public and private institutions of higher education in North Carolina currently operating programs similar to the proposed new degree program.

There are no other public or private institutions of higher education in North Carolina that offer a Ph.D. in Nanoscale Science. Duke University offers a Certificate in Nanoscience (as of Fall 2004) in which students obtain a Ph.D. degree in a core discipline (such as chemistry, physics, biology, engineering) and do additional coursework and laboratory work in nanoscale science in order to earn the certificate. Neither UNC Chapel Hill nor NC State University offer doctoral degrees or certificates in nanoscale science, but both universities have excellent research programs in nanoscale science and nanotechnology. Wake Forest University is also engaged in research in nanoscale science, as is NC A&T University.

On the national level, very few universities offer degrees in nanoscale science. The University of Albany offers a Ph.D. through its School of Nanosciences and Nanoengineering (www.albanynanotech.org/school_of_nano/index.cfm). The University of Washington offers a Ph.D. in nanotechnology that is associated with its Center for Nanotechnology (www.nano.washington.edu/education/proginfo.html). Numerous NSF IGERT (Integrative Graduate Education, Research and Training) grants for nanoscale science have been awarded to Ph.D. programs throughout the country.[10] Several institutions, namely Georgia Tech (www.chemistry.gatech.edu/News/NaST-web.pdf), the University of Pennsylvania (www.nanotech.upenn.edu/Certification%20v2.doc), and Drexel University (http://nano.materials.drexel.edu/DNI/education.html) offer Certificates in Nanotechnology.

3. Estimate the number of students that would be enrolled in the program during the first year of operation:

Full Time 6 Part Time 0

It is expected that the program will grow by six students per year and will reach a total enrollment of twenty-four students by Year 4.

4. Estimate the current and projected demand for graduates of the proposed new degree program. Provide documentation about the sources of data used to estimate demand figures.

The National Science Foundation predicts that roughly 2 million workers in nanoscale science and engineering will be needed by 2015,[7] 0.8-0.9 million of which will be needed in the United States.[8] Ph.D.-level workers will be needed to conduct research in academic and government laboratories and research and development in industry, to educate students at the college, university and community college levels, and to educate K-12 teachers.

In December, 2003, the Chemical Industry Vision2020 Technology Partnership (Vision2020, an industry-led organization focused on accelerating innovation and technological development) issued the report *Chemical Industry R&D Roadmap for Nanomaterials By Design: From Fundamentals to Function* (see www.ChemicalVision2020.org/nanomaterials roadmap.html). The report was based on scientific priorities developed at a workshop attended by top leaders in the chemical industry, universities, and government laboratories. The R&D priorities set forth in the report are in direct support of the National Nanotechnology Grand Challenges and are expected to produce products and processes that will significantly benefit the U.S. industry and society. A top priority of the Roadmap is to "implement strategies to attract and prepare a workforce for nanomaterial research and manufacturing." The report states that, "The rapid progress in nanoscale science discovery and its transition into innovative nanotechnology will require a highly trained workforce, **especially innovative scientists and engineers with doctoral degrees**." The report indicates that in order to produce the workers needed to maintain the dominance the U.S. has enjoyed during the past 50 years, it will be necessary for the United States to "implement an education and training strategy as soon as possible. Moreover, because the nanoscale bridges various disciplines, science education will need to integrate biology, chemistry, physics, and engineering."

The report identified several **needs** that will be **critical** in order for the nation to attract and prepare a workforce for nanomaterial research and manufacturing. These needs include, among others, providing interdisciplinary education for graduate students, and developing state-of-the-art nanomaterial curricula. The report also predicts that nanoscale science will develop into a full-fledged field by 2020, that undergraduate and graduate-level textbooks will include nanoscale fundamentals, and that specialized courses will be offered on most campuses. Faculty members with knowledge of nanoscale science will be needed to teach students and to develop educational materials.

Small Times, a business magazine that details technological advances, applications and investment opportunities in nanotechnology, reports that labor shortages of skilled workers in nanotechnology in industry, particularly at the Ph.D. level, are already beginning to show up. Start-up companies in particular seem to be "unaware of how few really experienced educated people there are in the various fields surrounding MEMS and nanotechnology."[11]

The establishment of a Ph.D. program in Nanoscale Science at UNC Charlotte could stimulate the development of start-up companies in the Charlotte and surrounding regions. Companies would be attracted to the region because of the research expertise the University would provide. In turn, the companies would provide employment opportunities for graduates of the program as well as less skilled workers. There are roughly 1100 start-up companies in nanoscale science in the United States.

The emergence of several websites devoted to employment opportunities in nanoscale science also indicates that there is, and will continue to be, a demand for graduates of the proposed new degree program. *Small Times* lists open positions in nanoscale science. *Working in Nanotechnology* (http://www.workingin-nanotechnology.com/) is a Web-based bulletin board that provides information on careers, education and professional training in nanotechnology and related fields. The site typically has about 70 jobs posted, ranging from the academic marketplace to corporate and government labs. The Foresight Institute, a non-profit organization for promoting understanding of nanotechnology and its effects, supports this website. The National Nanotechnology Initiative website has a page devoted to nanotechnology careers (http://www.nano.gov/html/edu/careers.htm).

In addition to acquiring knowledge and skills to work in nanoscale science, students of the proposed Ph.D. program will acquire depth of knowledge in a core science or engineering discipline, positioning them for employment opportunities in more traditional science and engineering fields. For example, a student in the proposed program who chooses to study chemistry as a core discipline will have ample opportunities for employment as a chemist in chemical industry, academics, and government labs. Graduates of our program would have the added advantage of having the skills and experience of working with scientists and engineers from a variety of disciplines. These skills are highly valued in industry (where much of the work is done in teams composed of scientists from a variety of disciplines) and other research settings.

5. Plans to Offer the Program Off-Campus in the First Year of Operation

There are no plans to offer the program away from campus.

6. Describe the procedures to be used to plan the proposed program. List the names, titles, e-mail addresses and telephone numbers of the person(s) responsible for planning the proposed program.

The program will be planned by a committee consisting of faculty members from Chemistry, Electrical and Computer Engineering, Mechanical Engineering and Engineering Science, Physics and Optical Science, and Biology, with input requested from the faculty of the participating departments. A planning committee was created to develop the Request for Authorization to Plan the Ph.D. Program in Nanoscale Science. The Chairs of the Departments of Biology, Electrical and Computer Engineering, Mechanical Engineering and Engineering Science, and Physics and Optical Science were consulted throughout the development of the Request for Authorization to Plan and confirmed that interested faculty members of their Departments would be available to participate in the proposed program. The members of the planning committee included:

Bernadette T. Donovan-Merkert (Committee Chair)
Professor and Chair, Department of Chemistry
bdonovan@email.uncc.edu, 704-687-4436

Angela Davies
Assistant Professor, Department of Physics and Optical Science
adavies@email.uncc.edu, 794-687-

Mahnaz El-Kouedi
Assistant Professor, Department of Chemistry
melkoue@email.uncc.edu, 704-687-4440

Jordan Poler
Associate Professor, Department of Chemistry
jcpoler@email.uncc.edu, 704-687-3064

Thomas Schmedake
Assistant Professor, Department of Chemistry
tschmeda@email.uncc.edu; 704-687-4011

Stuart Smith
Professor, Department of Mechanical Engineering and Engineering Science
stusmith@uncc.edu, 704-687-3969

Ed Stokes
Associate Professor, Department of Electrical and Computer Engineering
ebstokes@uncc.edu, 704-687-4142

The individuals listed above have agreed to continue to serve on the planning committee. The following individuals have also agreed to serve:

Lee Casperson
Professor and Chair, Department of Computer and Electrical Engineering
lcaspers@uncc.edu, 704-687-2302

Faramarz Farahi
Professor and Chair, Department of Physics and Optical Science
ffarahi@uncc.edu, 704-687-3440

Michael Hudson

Professor and Chair (beginning July 1, 2005), Department of Biology
mchudson@email.uncc.edu, 704-687-4048

Joanna Krueger
Associate Professor, Department of Chemistry
jkkruege@email.uncc.edu, 704-687-4913

Jayaraman Raja
Professor and Chair, Department of Mechanical Engineering and Engineering Science
jraja@uncc.edu, 704-687-3305

The curriculum for the proposed program will be designed to provide students with knowledge of nanoscale science, including an appreciation of perspectives of scientists and engineers of varied disciplines, plus depth of knowledge in a core science discipline. Graduates of the program will have developed the ability to communicate and collaborate effectively with scientists and engineers across a broad range of disciplines. A plan of study for each student will be developed collaboratively by the student and his/her research advisor and thesis committee, and subsequently approved by the Interdisciplinary Program Committee of the Nanoscale Science Ph.D. Program. This approach will provide the flexibility needed to meet each student's specific educational needs and interests

Degree requirements

Proposed degree requirements for the Ph.D. in Nanoscale Science are described below.

- ***Perspectives at the Nanoscale.*** Faculty members from across the UNC Charlotte campus present and discuss their research in nanoscale science and engineering in order to (1) demonstrate how scientists in different disciplines approach problem-solving at the nanoscale, and (2) expose the students to research opportunities for thesis work.

- ***Introduction to Instrumentation and Processing at the Nanoscale.*** Methods for manipulating, engineering, and characterizing nanoscale materials are introduced; applications and principles of their operation are discussed. Students acquire hands-on experience with selected laboratory methods in preparation for thesis research. Topics include, but are not limited to, scanning probe and electron microscopy methods, cleanroom technology, nanoscale optical and e-beam lithography, nuclear magnetic resonance, mass spectrometry, luminescence methods, interferometry, gel permeation chromatography, surface area analysis, and small-angle x-ray and neutron scattering.

- ***Group Rotations.*** Students interact on a regular basis with research groups in nanoscale science or engineering from at least three different departments at UNC Charlotte. Groups are selected so that each student is exposed to a broad array of research activities of the Nanoscale Science faculty. At the end of each rotation, the visiting student delivers a presentation to the visited research group, describing what the student has learned about the visited group's research activities.

- ***Group Project.*** An encapsulated, semester-long research experience designed to introduce students to laboratory work in nanoscale science and engineering. Teams of two to four students work on a short research project and present their results at the *Nanoscale Science and Engineering Colloquium* (described below).

- ***Interdisciplinary Nanoscale Lecture Courses.*** Each student completes the following courses:

  A. ***Nanoscale phenomena***. Topics include, but are not limited to, scaling phenomena; nano-optics (near-field optics, limits of lithography masks, nano-dots and nanoscale optical interactions); nanoscale mechanics; nanotribology; biological and biologically-inspired machines.

  B. ***Synthesis and characterization of nanomaterials***. Topics include, but are not limited to, quantum dots, metallic nanoparticles, carbon nanostructured materials and nanotubes, zeolites, organic-inorganic polymers, composite materials, solution-phase colloids, sol-gel process, silica spheres, porous silicon, photonic crystals.

  C. ***Fabrication and manufacturing of nanomaterials.*** Lithographic methods (CVD, PVD, e-beam, ion beam, magnetron, evaporation, spin coating, mask fabrication, developing resists); microelectromechanical systems and nanoelectromechanical systems; limits of conventional mechanical processing, electroforming, growth mechanisms (organic, inorganic, thermal); powders.

- ***Nanoscale Science and Engineering Colloquium.*** Students from the participating departments present seminars on current topics in nanoscale science and engineering to the faculty and student participants of the program. Presentations address thesis research, the current literature, group projects, and special topics.

- ***Collaborative Research Proposal.*** Effective strategies for designing and writing research proposals are discussed. Teams of two to three students each prepare an original, interdisciplinary research proposal on a topic in nanoscale science. Each team consults regularly with a panel of two to three faculty members who collectively approve of the proposal topic, provide feedback during the development of the proposal, and ultimately evaluate the proposal.

- ***Elective Ph.D. courses.*** Each student completes three additional courses from an approved list of Ph.D. courses offered in Chemistry, Physics and Optical Science, Mechanical Engineering and Engineering Science, Electrical Engineering, Biology or other approved disciplines.

- ***Visiting Speaker Seminar Program.*** Students attend weekly seminars of visiting speakers of the Nanoscale Science program or other approved programs on campus. Seminars are selected to best meet the educational needs of the individual student.

- ***General Science Proficiency Exam.*** By the end of the first year in residence, students are expected to demonstrate sufficient knowledge in chemistry, mathematics (including calculus) and physics, all at the introductory undergraduate level, by passing a General Science Proficiency Exam (GSPE) written and administered by faculty in the NANO Ph.D. program.

- ***Directed Graduate Research.*** Students conduct laboratory research for the thesis. Laboratory research is expected to begin by the first summer in residency.
- ***Admission to candidacy.*** By early in the 5th semester, the student presents and successfully defends, to his/her thesis committee, research completed thus far and proposed research for completion of the thesis.
- ***Thesis defense.*** The student completes a written research thesis, delivers a public seminar on the research, and defends the thesis to his/her thesis committee.

7. Describe the method of financing the proposed new program (e.g., potential sources of funding) and indicate the extent to which additional state funding may be required.

Staffing

The initial faculty needs of the proposed program are well met through existing faculty in the core disciplines. For the past several years, most of the participating departments have made targeted hires for faculty members who could support the teaching and research efforts of the proposed nanoscale science program. Thus, despite existing teaching and mentoring responsibilities, there are sufficient faculty resources to staff and operate the program at the proposed initial student admissions level (i.e., 6 doctoral students per year).

Future growth of Nanoscale Science faculty (and graduate student openings) will occur in response to anticipated enrollment growth at UNC Charlotte. For example, the Department of Chemistry’s staffing plan for 2005-2010 calls for a net increase of 4 faculty members by 2010. Many of these positions will be filled by faculty members who will support the Nanoscale Science Ph.D. program by teaching courses and mentoring students in research.

Physical Space

The Department of Chemistry will acquire roughly 10,400 sq feet of space in the Burson Building when the Department of Physics and Optical Science moves to the new building that will house the Center for Optoelectronics and Optical Communications beginning in early 2006. The Departments of Biology, Mechanical Engineering and Engineering Science, and Electrical and Computer Engineering will move to the new Science and Technology building, the new building for the Center for Precision Metrology, and the Optics Building during 2005 and 2006. Thus, no new space will be required to launch the proposed Ph.D. program.

Ability to Generate External Funding

The primary faculty members affiliated with the proposed program have obtained substantial external funding in support of their research (in excess of $10 million total per year) from agencies such as: the National Science Foundation; the National Institutes of Health; the Department of Defense; the Department of Energy; the National Institute of Standards and Technology; NASA; the American Chemical Society – Petroleum Research Foundation; INTEL; SEMATECH; the Whitaker Foundation; the Camille and Henry Dreyfus Foundation; and Research Corporation. Sustaining external funding is a high priority for the proposed program, thus faculty members of the program will continue activities to secure external research grants from federal agencies and industries. Nanoscale science is a top priority for funding by the National Science Foundation, which has established several initiatives devoted to this area (NIRT (Nanoscale Interdisciplinary Research Teams), Nanoscale Exploratory Research (NER), and Nanoscale Science and Engineering Centers, among others). NSF's IGERT (Integrative Graduate Education and Research Traineeship) program will be another likely source of funding to support graduate students, due especially to the interdisciplinary nature of the proposed nanoscale science program.

Financial Resources to Attract and Retain Students

Funding to attract and retain students will come from: (a) allocation of new assistantship resources and tuition wavers to the nanoscale science program; and (b) funding from external grants.

We propose to add six new teaching assistants (with tuition waivers) during the first year of the program and an additional six teaching assistants (with tuition waivers) during the second year. These would be supplied by the Graduate School. If needed, some of the Chemistry M.S. teaching assistantships could be used to support the Nanoscale Science Ph.D. program, but this would only be done to a small extent so as not to harm the Chemistry M.S. program (the program is productive; its graduates are accepted to top-rate Ph.D. programs and are employed by leading chemical companies). Graduate students would be supported for the first two years as teaching assistants and then afterwards as research assistants on external grants.

References

1. For a comparative view of commonly known items and nano-sized entities, see www.nano.gov/html/facts/The_scale_of_things.html.
2. For the text of Feynman's address, see http://www.zyvex.com/nanotech/feynman.html.
3. For congressional addresses on this topic delivered by leaders in the field of nanoscale science and technology, see addresses delivered by: (a) Eugene Wong, assistant director of Engineering of the National Science Foundation (www.house.gov/science/wong_062299.htm); (b) Richard Smalley, Nobel Laureate and Professor of Chemistry at Rice University(www.house.gov/science/smalley_062299.htm), and (3) Ralph Merkle, Research Scientist (Xerox) and Senior Research Associate, Institute for Molecular Manufacturing (www.house.gov/science/merkle_062299.htm).
4. From the Web page for the National Nanotechnology Initiative: (http://www.nano.gov).
5. See http://www.nsf.gov/sbe/srs/infbrief/nsf04320/nsf04320.pdf
6. Roco, M.C. *The US Nanotechnology Initiative after 3 years (2001-2003)*(Journal of Nanoparticle Research 2004, *6*(1), 1-9).
7. Roco, M.C.; Bainbridge, W. (eds) *Societal Implications of Nanoscience and Nanotechnology* (National Science Foundation, Arlington, VA, 2001).
8. Roco, M.C. *Converging science and technology at the nanoscale: opportunities for education and training* (Nature Biotechnology, 2003, 21(10), 1-3).

9. For the 2004 Strategic Plan of the NC Economic Development board, see http://149.168.102/Upload/assets/EDB_Strategic_Plan_2004_final.pdf The quoted action item may be found on page 18.
10. See www.nsf.gov/igert.
11. http://www.smalltimes.com/document_display.cfm?document_id=7817

This intent to plan a new program has been reviewed and approved by the appropriate campus committees and authorities.

Chancellor ______________________

Appendix

Faculty Research Interests

Dr. Vasily N. Astratov (Physics and Optical Science) The Astratov group focuses on all-optical circuits based on evanescent optical coupling between spherical and cylindrical microresonators positioned with nanometer scale precision on a single chip.

Dr. Kenneth Bost (Belk Distinguished Professor, Biology). The Bost group works in the area of immunology. Specific research efforts relevant to nanoscale science include biomodification of nanostructured surfaces for tissue engineering.

Dr. Robin Coger (Mechanical Engineering and Engineering Science). Dr. Coger's research focuses on applying device design, computational modeling, and material testing to solve biomedical engineering problems in tissue engineering and cryopreservation. Areas of interest related to nanotechnology include investigating the interactions of cells with micropatterned surfaces, and the use of nanoparticles in tissue engineering applications.

Dr. Brian T. Cooper (Chemistry) The Cooper group is investigating a novel capillary electrophoretic technique, based on differential surfactant binding, for characterizing conformational isoforms of proteins. The group is also interested in the potential application of microfabricated devices with nanoscale features to new modes of protein separation or detection.

Dr. James Cuttino (Mechanical Engineering and Engineering Science). Dr. Cuttino has been involved in the development of precision actuators and instrumentation. His research has spanned the range of precision fast tool servos to the development of a portable Josephson junction voltage standard based on an active cryogenic system. Principal areas of interest include dynamics, mechatronics, instrumentation, and machining.

Dr. Kasra Daneshvar (Electrical and Computer Engineering) Research in the Daneshvar group focuses on the application of nanoparticles for all-optical devices. A typical quantum dot (QD) with diameter of 3 nm contains only few hundred atoms. Therefore, saturation in optical absorption can take place, in threshold power density of photons several orders of magnitude below the typical values for most solids, ~ MW/cm^2 range. This low value of threshold opens the door for a wide range of optoelectronic applications. Among these is the all-optical Analog to Digital converter (ADC). An absorber with low saturation intensity can be used in series or in parallel to set the threshold for the significant bits in a sampled analog signal.

Dr. Angela D. Davies (Physics and Optical Science). The Davies group focuses on research metrology advances for precision micro-optics components to assess dimensional form with nanometer scale uncertainty.

Dr. Matthew Davies (Mechanical Engineering and Engineering Science). Dr. Davies came to UNC Charlotte from NIST where his research focused on measurement of the dynamic and plastic phenomena in high-speed machining. He continues research in precision manufacturing and dynamics as well as biomechanics and micro-optics.

Dr. Bernadette T. Donovan-Merkert (Chair, Chemistry). The Donovan-Merkert group is interested in electrochemically-promoted reactions of organometallic complexes. The group is developing new hybrid films containing quantum dots or lanthanide complexes for phosphorescence/ electroluminescence applications, and is exploring the use of nanostructured electrode materials for applications in asymmetric catalysis.

Dr. Thomas D. DuBois (Chemistry). Dr. DuBois' research addresses modeling of molecular and nanomaterials using mechanics, electronic and dynamic computational methods. Work with Dr. Jordan Poler focuses on the interaction of carbon nanotubes with transition metal complexes and transition metal clusters formed from a variety of ligand assemblies.

Dr. Mahnaz El-Kouedi (Chemistry). Research in the El-Kouedi group focuses on the construction and use of nanoparticulate substrates for biological and chemical sensing applications. These new nanomaterials have unique electronic and optical properties that can be tuned to enhance detection limits. The group is also exploring the use of nanoscale surfaces for catalysis applications.

Dr. Horatio Estrada (Mechanical Engineering and Engineering Science). Research in the Estrada group focuses on MEMS-based sensors and actuator developments.

Dr. Michael A. Fiddy (Physics and Optical Science and Electrical and Computer Engineering, Director of the Center for Optoelectronics and Optical Communications). Dr. Fiddy's research focuses on the development of theoretical and numerical techniques for determining optical structures with refractive index variations having sub-wavelength (tens of nm) scales and which guide and scatter light in a prescribed fashion. Co-operative enhancements of optical nonlinearites in nanocomposites are also addressed.

Dr. Kenneth E. Gonsalves (Celanese Acetate Distinguished Professor, Chemistry) New initiatives for developing novel resist materials for nanolithography (EUV, EB and X-ray) are underway in the Gonsalves group. Concepts of nanostructured materials technology developed in the Gonsalves laboratory are now being applied to submicron and nano- (below 100 nm) structures for microelectronics and biotechnology. Dr. Gonsalves is the lead organizer of UNC Charlotte's first nanotechnology conference that will be held during October, 2005.

Dr. Mohamed-Ali Hasan (Electrical and Computer Engineering). The Hasan group focuses on molecular beam epitaxy (MBE) for the construction of nanoscale materials, including (1) growth of single crystalline cubic SiC on Si using compliant nanoscale seed crystals employing an economical, environmentally friendly method that utilizes a non-toxic gas, trimethylsilane, and (2) growth of single crystalline hexagonal AlN(001) and GaN on Si(111) using surface-reconstruction induced epitaxy. These materials are useful substrates for nanoscale optoelectronic devices, and also can be used for HFETs.

Dr. Tsing-Hua Her (Department of Physics and Optical Science). The Her group focuses on multiphoton-initiated processes for micron/submicron/nanofabrication.

Dr. Robert J. Hocken (Mechanical Engineering, Director of the Center for Precision Metrology). Dr. Hocken's research interests include precision machine design, dimensional metrology and scanning probe microscopy. In addition to directing UNC Charlotte's Center for Precision Metrology (an NSF IUCRC center incorporating an affiliates consortium comprising major US Manufacturing industries), he is also involved in SINAM, an NSEC, funded by NSF and partnering with UCLA, UCSD, Stanford, Berkeley and HP labs.

Dr. Michael Hudson (Chair (beginning July 1, 2005), Biology). Research in the Hudson group investigates the interaction of *Staphylococcus aureus,* the most common organism associated with osteomyelitis (infection of the bone) with mouse and human osteoblasts (cells involved in bone formation). Research efforts in nanoscale science include the use of nanomachined polymer surfaces for promoting osteoblast cell adhesion.

Dr. Joanna K. Krueger (Chemistry). The Krueger group works in the area of biophysical chemistry. Probing of the nanostructural features of proteins using small-angle X-ray and neutron scattering with a contrast variation technique was instrumental in assembling a more global picture of how signals are transduced between Ca^{2+}-activated calmodulin and its kinase target, myosin light chain kinase.

Dr. Patrick Moyer (Physics and Optical Science). Dr. Moyer's research includes integrated optics and nanoscale optical spectroscopy. Recent research has involved the role of quantum confinement vs. that of surface molecules in determining the light emission mechanism of porous silicon. In addition, he has studied the time-dependence (on a millisecond time scale) of surface enhanced Raman scattering of single carbon domains on single silver nanoparticles. Dr. Moyer has worked in industry as a scientist and engineer designing and developing scanning probe microscopes for the study of nanoscale properties of materials and biological samples.

Dr. Arindam Mukherjee (Electrical and Computer Engineering) Dr. Mukherjee's research focuses on bio-inspired electronic design and design automation for inherently faulty nanoscale circuits.

Dr. Brigid Mullany (Mechanical Engineering and Engineering Science). Dr. Mullany's group is concerned with the generation and measurement of precision engineered surfaces. Ultra-smooth surfaces have average roughness values of less than 0.2 nm and the generation of such surfaces depends on the type and size of abrasive particles used in the polishing processes. Research is concerned with determining how nano abrasive particles and their surface charges interact with the workpiece in removing material and generating these ultra smooth surfaces.

Dr. Jordan C. Poler (Chemistry). Nanoscale molecular assemblies enable the design and manipulation of matter with unprecedented fidelity. With these novel assemblies, the Poler group is working towards tailoring the properties of new materials and developing new devices. Supramolecular assemblies are being investigated for potential applications in 3D nanostructuring, optical switching, and sensors.

Dr. Daniel Rabinovich (Chemistry). The Rabinovich group is interested in synthetic and structural inorganic chemistry, with applications to bioinorganic chemistry. Research relevant to nanoscale science focuses on the synthesis and use of multidentate thioethers to control the size and shape of gold nanoparticle assemblies with potential applications as sensors and in catalysis, information storage and microelectronics.

Dr. Jay Raja (Chair, Mechanical Engineering). Dr. Raja's research is in the field of surface fine feature measurement and characterization, commonly referred to as surface metrology. His recent work concentrates on the development of web-based surface metrology analysis software for industry use as well as addressing emerging issues in 3 dimensional analysis and identification and characterization of structured surfaces.

Dr. Arun Ravindran (Electrical and Computer Engineering) Dr. Ravindran's research addresses opportunities and challenges of nanoscale electronics through new circuit design paradigms. His group investigates current design techniques to control leakage in nanoscale CMOS transistors; realization of analog signal processing blocks using carbon nanotubes, single electron transistors, quantum dots, and bio-tissue devices; and the use of digitally assisted and bio-inspired techniques for fault-tolerant nanoscale circuits systems.

Dr. Thomas A. Schmedake (Chemistry). The Schmedake group explores the remarkable effects that are manifested when light is confined to a volume approaching the wavelength of light (<500 nm). At this size certain frequencies of light become resonant with the optical cavity. The group is attempting to exploit this phenomenon for the rational design of better sensors, photocatalysts, and optical devices.

Dr. Wade Sisk (Chemistry). The Sisk group investigates the photostability, photoluminescence, and photoconductivity of dyes dispersed in polymer matrices. One goal is to understand the mechanisms of photodegradation and to employ methods to decrease the rate of photodegradation. Applications of this research include: solid-state dye lasers, waveguides, organic light emitting devices (OLEDs), read/write disks (DVDs), and photofading of dyed fabrics.

Dr. Stuart T. Smith (Mechanical Engineering). Dr. Smith's research focuses on the development of instrumentation and sensor technologies, including advanced signal processing techniques, for measurement of surface profile, micro-geometry and displacements, primarily aimed towards the challenge of atomic scale discrimination and modifications. As a consequence of these efforts many investigations in the fields of instrument and sensor design, surface contact phenomena, flexure mechanisms and slideway design have been undertaken.

Dr. Ed Stokes (Electrical and Computer Engineering). The Stokes group is working to develop brighter and more efficient solid-state light sources for application general illumination, spectroscopy, displays, and communications. In current-generation epitaxial III-nitride semiconductor light emitting materials, nanostructure plays a key role in maximizing light emitting device efficiency. Wavelength tunability is achieved by the quantum size effect, and quantum confinement serves to minimize non-radiative recombination through crystal defects. The Stokes group is expanding on these concepts by developing new nanostructured materials with II-VI semiconductor quantum dots, synthesized in liquid phase, and integrated through novel processing into III-nitride semiconductor epitaxial materials.

Dr. Thomas J. Suleski (Physics and Optical Science). The Suleski group focuses on the development of novel nanofabrication techniques. Simulation, design, fabrication, and characterization of micro- and nano-optical devices and systems are explored.

Dr. Raphael Tsu (Electrical and Computer Engineering). Dr. Tsu is an international expert on nanoscale electronics and optoelectronics. His research incorporates theoretical and experimental studies on the quantum nature of properties of nanoscale materials, such as the dielectric function and capacitance. The Tsu group reported some of the pioneering work on quantum wells and quantum well superlattices.

Dr. Robert Wilhelm (Mechanical Engineering and Engineering Science). Dr, Wilhelm's research interests include metrology, signal processing, and computer automation for synthesis, analysis, and fabrication. He is the associate director of the UNC Charlotte Center for Precision Engineering. Current research interests include metrology techniques at the nano-scale based on self-assembling lattices and chirality.

Dr. Terri Xu (Mechanical Engineering and Engineering Science). Dr. Xu's research focuses on the synthesis and characterization of nanomaterials and nanostructures; the fabrication of nanocomposites and investigations of their properties; and nano-material based devices for sensor applications.