Graduate Program in Nanotechnology

1. Intellectual Rationale: Over the past decade, massive federal and state investments into nanoscience have resulted in a number of scientific breakthroughs and the emergence of clearly identifiable application areas for commercial development. With the increasing utilization of nanotechnology in consumer products, companies in the Silicon Valley are in need of a skilled workforce, in particular on the graduate level, for research and development efforts. Here, we propose the implementation of an expansion of our current MS degree program, with three areas of emphasis in Nanotechnology that uniquely match UCSC's areas of strength, existing SV industries, and leverage the NASA Ames Research Center:

Emphasis 1: Data Science

The School of Engineering's historical emphasis on computing-centered disciplines positions us uniquely as leaders in data science and applications in a time when unprecedented volumes of data are generated, stored, and handled. The proposed Nanotechnology graduate program covers the physical implementation (hardware) aspects of data science. For example, emerging data storage technologies are based on spintronics or memristor approaches, and EE faculty have close collaborations with global industry leaders in these fields such as HP, Samsung, and Western Digital. These companies need to respond to the many simultaneous disruptions hitting the world of information technology: the end of traditional Moore's Law scaling of the number of transistors in a circuit, the explosion in the growth of data that is being collected that people want to analyze, the limitation in the amount of electrical power that is available for computers of all form factors, and the rise of new technologies, especially non-volatile storage-class memory and integrated photonics for interconnect.[1]

Emphasis 2: Personalized Medicine

SoE has several internationally leading groups in different areas of the rapidly growing field of personalized medicine, including bioinformatics for genomics and proteomics, nanopore science, optofluidic devices for point-of-care diagnostics, and bio-imaging. The proposed specialization area provides students with a broad education ranging from overview courses to specialized areas such as integrated biophotonics and Bio-MEMS.

Emphasis 3: Energy Storage and Conversion

EE faculty have active research in energy storage and conversion, with collaborations that include industry and NASA Ames Research Center. This includes innovations for using nanotechnology-based materials for storing electrical energy (ultracapacitors), in addition to the conversion of mechanical and heat energy (piezoelectric and thermoelectric, respectively) into electrical energy.

When considered as part of an engineering system, the nanotechnology emphasis areas can be considered as components to support a well-balanced degree program. For example, energy storage and conversion can be used to provide electrical power for medical devices and computational analysis. The EE department is in excellent position to lead the development of these cutting-edge degree programs in nanotechnology. The EE curriculum already contains 10 graduate courses that fit naturally with this program (see course listings in attached file "MS in EE SV Courses). Moreover, EE has already initiated a successful MS program that is showing exponential growth. A large fraction of the faculty is already involved with SV industry in different areas of nanotechnology, the NASA Ames Research Center, and teaching and education in the valley. Based on this excellent starting position, additional courses (e.g. nano-optics) will be added, and the curriculum will be broadened to include offerings from other departments, in particular biomolecular engineering.

In summary, the proposed Graduate Program in Nanotechnology addresses the workforce needs of Silicon Valley industry, while providing distinct areas of specialization that are tailored to both the unique strengths of the SoE and growing industrial applications.

2. Involvement of Existing Faculty: A listing of the teaching involvement of our existing faculty, including two adjunct faculty members in SV, is included in the attached file "MS in EE SV Courses." The faculty members' research interests are in the same areas as the course offerings they are listed as teaching. In addition to our existing faculty, we will tap rich "human" resources available across the SV industries. For instance, Dr. R. Stanley Williams (Hewlett-Packard Co., Vice President and Senior Fellow) who used to be a professor in Chemistry at UCLA expressed his strong interest for involvement as an adjunct faculty member with our proposed degree program. Dr. Williams is one of the leading scientist in nanotechnology and advanced electronics and has been supporting Prof. Kobayashi's research activities by providing HP's resources to Kobayashi's graduate students over the last six years. We believe that EE can develop similar arrangements with other senior leaders throughout SV.

We also have strong collaborations in the area of nanotechnology both within the School of Engineering and Physical & Biological Science including:

SoE/CE: William Dunbar, Nadir Pourmand, Mark Akeson

PBSci/Chemistry: Shaowei Chen, Yat Li, Jing Zhang

PBSci/Physics: Sue Carter, Art Ramirez

3. Enrollment Goals and Connections to Campus Research: The Electrical Engineering department has initiated an aggressive MS degree program in Silicon Valley since 2013. Before this initiative, we had on average 5-7 MS students each year in the EE department. Since we started this program, we currently have 38 MS students and we project that we will admit another 30-40 new students this year if our new MS degree is approved by the Graduate Council for the 2015-16 academic year. The EE department is one of the fastest growing graduate programs at UCSC and if resources are dedicated to our department, we project to have more than 100 MS students with the majority of them being from foreign countries, most notably China and India (see supplementary file 2015 MSEE Applicant Listing). However, this goal can only be achieved if we can quickly replace our faculty members that recently left our department and the university allocates new resources as described below for the UCSC Silicon Valley division of the EE department. The connection to campus research are in our three areas of emphasis (Data Science, Personalized Medicine and Energy Storage and Conversion), as described above. Some of our research programs are currently tightly coupled to companies in SV such as HP and Samsung and to the NASA Ames Research Center.

4. Target Market and Evidence of Demand: There is a demonstrated demand for graduate degrees in Silicon Valley with a large number of students pursuing the MSEE, ~500 at San Jose State, ~500 at Stanford. Our program would provide an attractive alternative that is intermediate in terms of both cost and prestige. EE has recently demonstrated the capability to rapidly grow a new Master's program in Silicon Valley (47 MS students admitted since the MSEE program began in 2011, the number of new admits approximately doubling each year: 11/12-2, 12/13-5, 13/14-15, and 14/15-25). This year we have received over 150 applications for our MSEE program, which is more than we can handle with our current faculty (see supplementary file "2015 MSEE Applicant Listing"). From a different perspective, currently there are a large number of experienced employees accumulating 10+ years of service in industry after obtaining their B.S. degree. These employees seek a path to obtain an advanced degree (i.e. M.S.) to prepare themselves for promotion.[2,3]

5. Outline of Additional Resource Needs:

1. One new FTE in Nanotechnology to build up our MSEE program in SV that currently includes two teaching adjunct faculty members (Prof. Michael Oye and Prof. Toshishige Yamada) in addition to our faculty members who commute from SV and have taught remotely to UCSC from SV previously. This person would have a strong connection to local industry and NASA Ames, and would most likely come from one of those entities. An example would be Prof. Nobby Kobayashi who joined UCSC from

HP and is still strongly coupled into their research program. His students continue to use the research facilities at HP Labs, as described above.

2. Office space for the new FTE and their graduate students.
3. Dry lab space for the new FTE in SVC with the potential for additional space near campus at 2300 Delaware Avenue.
4. Wet lab/fabrication needs of the new FTE in SV would be fulfilled at shared cleanroom resources. We believe it would be prohibitively expensive to build cleanroom space in SV, but there are already several options for using existing facilities in SV. The typical cost for membership in these facilities is approximately $50,000/year. These costs could initially be included in the start-up package and could later be covered by extramural grants. Some examples of shared infrastructure in the SV area include:
    a. The Stanford Nanofabrication Facility (SNF) which serves academic, industrial, and governmental researchers. SNF is supported by NSF through the National Nanotechnology Infrastructure Network (NNIN).
    b. The Berkeley Sensor & Actuator Center (BSAC), a National Science Foundation Industry/University Cooperative Research Center for Microsensors and Microactuators. BSAC is also a member of the National Nanotechnology Infrastructure Network (NNIN), supported by the National Science Foundation, serving the needs of nanoscale science, engineering and technology.
    c. The Marvell NanoLab, located in the CITRIS headquarters building, Sutardja Dai Hall, includes more than 15,000 sq. feet of Class100 and Class1000 cleanroom. The Marvell NanoLab is a shared research center providing more than 100 Principal Investigators and over 500 academic and industrial researchers a complete set of micro- and nano-fabrication tools.
    d. The W.M. Keck Center for Nanoscale Optofluidics at UC Santa Cruz has a dedicated nanofabrication facility in 268 Baskin Engineering. The lab houses a FEI Quanta 3D FEG dual beam SEM/FIB nanofabrication instrument for fabrication, imaging, and characterization of nanoscale optofluidic devices. In addition, researchers have access to the shared microfabrication cleanroom facility in Baskin Engineering and to state-of-the art research facilities in the center members' labs.
    e. The University of California Santa Cruz Materials Analysis for Collaborative Science (UCSC MACS) Facility is an advanced microscopy and materials facility located at NASA Ames Research Center in Mountain View, CA. The MACS Facility is available for use by government, academic, and commercial users throughout the Silicon Valley region. The instrumentation is centered on a state-of-the-art transmission electron microscope as well as advanced SEM imaging. NASA Ames MACS is located in the Advanced Studies Laboratories (ASL), a collaborative partnership of NASA Ames Research Center and the University of California Santa Cruz launched in 2005. The ASL, situated at NASA Ames building N239, is a research and learning environment for emerging Bio-Info-Nano practices and techniques that leverages the talents and resources of UC, NASA, and academic and industrial partners.
5. A coordinator to facilitate day in and day out operations at SV, facilitate test and homework administration and telecast operations. This would be a person similar to Durga Pisharam, Instructional Support Coordinator, in BSoE Faculty Services. This coordinator could be shared across a number of professional degree programs in SV.
6. Course telecasting facilities.
7. Common work space for MSEE students.

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[1] K2I Distinguished Lecture - "The Machine: The HP Memristor Solution for Computing Big Data", Stanley Williams, HP Senior Fellow, Vice President, Foundational Technologies Hewlett-Packard Laboratories , Rice University, November 6, 2014.
[2] Source: Private communication between Kobayashi and R. Stanley Williams, Hewlett-Packard Co. (Palo Alto, CA) Vice President and Senior Fellow.
[3] Source: Private communication between Kobayashi and Ravi Mullapudi, President/CEO at Tango Systems, Inc. (San Jose, CA).

EE 211 Introduction to Nanotechnology
Introduction to underlying principles of nanoscience and nanotechnology. Intended for multidisciplinary audience with a variety of backgrounds. Introduces scientific principles and laws relevant on the nanoscale. Discusses applications in engineering, physics, chemistry, and biology. Prerequisite(s): course 145 or consent of instructor. H. Schmidt (UC campus only)

EE 212 Introduction to BioMEMS
Oriented to general engineering and science students. Topics included are: 1) microfabrication of silicon, glass, and polymer materials; 2) microfluidics and electrokinetics; 3) sensors, actuators, and drug-delivery systems; 4) micro total-analysis systems and lab-on-a-chip devices; 5) detection and measuring systems; 6) genomics, proteomics, DNA, and protein microarrays; 7) emerging applications in medicine, research, and homeland security; 8) packaging, power systems, data communication, and RF safety; and 9) biocompatibility and standards. Recommended for advanced undergraduates and graduate students in bioengineering, electrical engineering, chemistry, and health-related fields including biochemistry, molecular and cellular biology, physiology, and genetics. Enrollment restricted to graduate students, or by permission of the instructor. J. Kubby

EE 213 Nanocharacterization of Materials
Covers the many characterization techniques used to characterize materials from volumes less than one cubic micrometer, including the basic physics of each method, the methodology used to get quantitative results, and the advantages and limitations of each technique. Pre-requisite(s: Enrollment restricted to graduate students, or to undergraduates majoring in engineering or science by permission of instructor. M. Isaacson

EE 215 Micro-Electrical-Mechanical Systems (MEMS) Design
Introduction to MEMS technology: covers basic microfabrication technologies, the governing physics for MEMS devices in different energy domains (mechanical, electrical, optical, thermal, and fluidic). Fabrication and design of MEMS devices illustrated using examples of existing research prototypes and commercial products. Students design, lay out, and fabricate an optical MEMS deformable mirror device for applications in adaptive optics. Students are billed a materials fee. Prerequisite(s): courses 135, 145, and 211; and Physics 5A, 5B, and 5C. Enrollment restricted to seniors and graduate students. May be repeated for credit. J. Kubby

EE 216 Nanomaterials and Nanometer-scale devices
Materials controlled at nanometer-scale will revolutionize existing technologies. Course offers opportunities of learning materials that exhibit peculiar physical characteristics at the nanometer scales. Course also includes discussions of unique device architecture based on materials crafted at the nanometer scale. N. Kobayashi

EE 218 Fundamentals of Nanoelectronics
Covers microscopic theory of electron transport in nanoelectronic devices and transistors. Topics include: ballistic transport; quantum conductance, NEGF-Landauer formalisms; molecular conductors; graphene and carbon nanotubes, quantum resonant tunneling devices; nanotransistors; and spintronics.

EE227 Fundamentals of Semiconductor Physics
Semiconductor Physics is examined for advanced new materials and devices. Discusses how familiar concepts are extended to new electronics. Intended for audience interested in EE, Physics, and Materials

Science applications. Good familiarity with basic Electromagnetism and Quantum Physics is assumed. T. Yamada

EE236: Integrated Biophotonics
Covers use of integrated optics for study of biological material; fluorescence spectroscopy, single molecule detection, optical tweezers, layered dielectric media, hollow-core waveguides, photonic crystals, optofluidics, biophotonic systems, and applications. Prerequisite(s): course 233 or equivalent. Enrollment restricted to graduate students. H. Schmidt (UC campus only)

EE293 Advanced Topics in Electrical Engineering

Engineering Solid State Materials
This graduate-level course will address principles of solid state materials with applications for engineering research. Materials-based fundamentals will be covered for devices, such as LEDs, lasers, photodetectors, modulators, and high speed transistors. Principles discussed during the course will be applied toward completion of a Research Paper and Class Presentation(s). Paper and Presentation do NOT have to involve any laboratory work.

Tentative list of core topics to be covered:

- Energy Bonds and Bands
- Electron Waves in Semiconductors
- Semiconductor Materials Processing
- Optical & Electrical properties of Materials
- Calculation of bandstructure for quantized semiconductor heterostructures

Instructor: Michael M. Oye, Ph.D.
Assistant Adjunct Professor, Department of Electrical Engineering
Director, Materials Analysis for Collaborative Science (MACS) Facility
Co-Director (UCSC), Advanced Studies Laboratories (ASL)
Associate Director, Aligned Research Program (ARP)
University of California Santa Cruz
1156 High St.; Mail Stop SOE2
Santa Cruz, CA 95064

Semiconductor Processing

This course addresses materials and fabrication principles related to semiconductor processing. The preparation of silicon, III-V compounds, and dielectric thin films will be described. We will focus on bulk growth and thin film deposition techniques, diffusion, ion implantation, and standard device fabrication sequences. These topics will emphasize the principles in electronic materials processing for fabrication of semiconductor electronic devices.

Tentative list of subjects:

- Photolithography
- Oxide formation
- Diffusion

- Thin Film Deposition
- Ion Implantation
- Bulk Crystal Growth
- Epitaxial Growth
- Characterization

Optional semiconductor processing laboratory project

The course will provide an opportunity for an optional hands-on laboratory project supported by Foothill College within the Advanced Studies Laboratories (collaborative partnership between UCSC and NASA Ames) at NASA Ames Research Center in Silicon Valley. The project will be related to subjects covered in the course.*

*Access to NASA Ames requires issuance of a NASA Visitor badge. Since approvals for Foreign Nationals require additional processing time, it is likely that only U.S. Citizens and U.S. Permanent Residents could participate. There are limitations on project availability and scope; criteria will be described in class. Participation in the optional laboratory project is not required and will have no impact on the course assignments and/or final grade.

Instructor: Michael M. Oye, Ph.D.
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