Curriculum Innovations in Microelectronic Engineering

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Abstract

The incredibly shrinking transistor has revolutionized the science, technology and applications of miniaturization not only in electronics but also in mechanics, photonics, biology, magnetics and chemistry. The extension of conventional microelectronics to new frontiers that include MEMS, nanotechnology, flexible electronics and biotechnology is inevitable. The development of a necessary work force for these burgeoning technologies would require students to be able to access courses outside their specific discipline.

The department of microelectronic engineering received a one year department level reform planning grant entitled “Undergraduate Co-op Based Concentration Curriculum in MEMs and Nanotechnology” in the year 2003. During this time, an institute wide review of engineering curricula was undertaken. Strategically designed flexible curricula that allow room for taking courses in other programs were seen necessary for promoting multidisciplinarity, wider job growth opportunities and enrollment in engineering and science curricula. In 2004, RIT Provost instituted the ‘flexible’ curriculum initiative – requiring colleges to develop curricula that will allow a five-course minor in each program without compromising the core strengths and consistency with the ABET guidelines.

With the support provided by the National Science Foundation for this one year planning grant and the Provost’s vision, the department of Microelectronic Engineering received an implementation grant to institute a major department level reform – offering a *semiconductor processing* minor for other science and engineering programs promoting access to state-of-the art semiconductor fabrication facilities to students from other programs; crafting a five course elective sequence within the existing curriculum by eliminating legacy material and course consolidation; outreach programs for targeting larger and diverse participation in preparing workforce for the nation’s future high tech industry; and enhancing student learning through co-op and service.

Introduction

Given the rate of technology innovation that the semiconductor industry has exhibited, it would come as no surprise if device manufacturers continued on a pace of rapid technology developments in design, manufacturing technology and new packaging implementation. Moore's Law of smaller, faster, cheaper devices will continue pushing faster clock speeds on microprocessors and increasing storage capability in memory devices. Manufacturing innovations have demonstrated readiness to implement 65nm and 45nm nodes on 300mm wafers. New process technologies (nanolithography, atomic layer deposition, plasma doping, laser rapid thermal annealing, chemical mechanical planarization, electrochemical deposition etc), substrate engineering (strained silicon, silicon on insulator (SOI), and SiGeOI, new materials (high and low k dielectrics, silicides, ferroelectric and magnetic), novel packaging (flip chip, wafer level redistribution layer) and software developments have exceeded predictions. On the device side, sub 25nm prototype MOSFETS have already been demonstrated. On the system side, current trends include increasing levels of integration; analog/mixed-signal design; high-speed communications chips; systems-on-a-chip (SoCs); and custom chips.

The semiconductor industry is rapidly reaching a point in its evolution where it will encounter serious challenges in the form of quantum effects and atomic level statistical fluctuations. As current lithographic methods reach their limit, the tools used in the development, manufacture, and testing of CMOS must be based on nanotechnology. Direct-write e-beam technology is an example of a nano-enabled tool that is already used for production. However, the true benefits of nanotechnology lie in leveraging the nanoscale properties of new materials to build new products. The biggest impact that nanotech will have on the semiconductor industry will fall outside the CMOS paradigm [1].

Nanostructures and nanodevices, which typically perform some electronic functions, and are perhaps the most critical subset of nanotechnology, essentially involve the manipulation of materials at the atomic level. Explosive growth of nanoelectronics, from NEMS and optoelectronics to sensors used in biological applications is anticipated. These fields will grow between now and 2030, and new types of nanosystems are likely to be developed as well [2]. The opportunities in nanoelectronics are considerable. It is predicted that CMOS will be supplemented by novel nano-enabled solutions, such as those described above. Prudent semiconductor manufacturers must plan for nanotech's impact on their businesses today and prudent educators must plan for educating a high tech work engineering workforce [3, 4].

Microelectronic Engineering at RIT

Undergraduate Program

The Bachelor of Science program in Microelectronic Engineering at RIT started in 1982 with basic PMOS process on 2" wafers. Today the program supports a complete 4 and 6 inch CMOS line equipped with diffusion, ion implantation, plasma PVD and CVD processes, electro-deposition, chemical mechanical planarization, I-line and deep UV wafer steppers, Perkin Elmer MEBES III electron beam mask writer, and device design, modeling and test laboratories. The program remains the only ABET (Accreditation Board for Engineering and Technology) accredited Bachelor of Science program granting a degree in Microelectronic Engineering. The program, which includes 5 quarters of required co-op, currently has over 130 undergraduate students. The Co-op is a program commences after the second year, and students alternate school with paid employment in the semiconductor industry. The laboratories at RIT include the largest university clean room for IC fabrication and are partially supported by our industrial affiliates, who provide curriculum input and support through donations of equipment [5, 6].

Graduating students from this program are also very successful in M.S. or Ph.D. graduate programs in electrical engineering, materials science or related engineering or science fields.

Several graduates have achieved leadership roles in the semiconductor industry. Currently, RIT has been awarded one of the New York State Office of Science and Technology (NYSTAR) Centers and the facility has expanding to incorporate MEMs, microsystems and photonics research areas.

Graduate Programs

The success of the BS program led to the development of graduate programs in microelectronic engineering. A unique Master of Engineering program in Microelectronic Manufacturing Engineering is offered through distance learning to allow engineers with traditional engineering and science BS degrees working in the semiconductor industry [7]. The Master of Science program emphasizes on research for preparing students for doctoral studies and for workforce development critically needed as addressed in the Semiconductor Industry Association's (SIA) International Technology Roadmap for Semiconductors (ITRS) [8].

RIT has developed a new combined five-year BS-MS program consisting of Bachelor of Science degree in Microelectronic Engineering and Masters of Science degree in Materials Science and Engineering. It is cross-disciplinary program designed to prepare students to meet the challenges requiring novel materials in modern integrated devices and circuits, MEMs and sensors. This program will foster education and research in nanoscale materials and devices. The proposed concentration curriculum will supplement this program very well.

A unique educational and research program that leads to a Ph.D. in Microsystems Engineering was instituted in 2002. This multi-disciplinary program builds on the strengths in microelectronic fabrications, photonic, imaging and micro-power research programs at the institute. Students are involved in cutting edge research and have access to modern facility, the largest of its kind in any academic institution. The program has graduated six students in the last four years.

Table I and Fig. 1 summarize curriculum development and technological achievements in microelectronic engineering at RIT over the last 25 years.

TABLE I: CURRICULUM INNOVATIONS LED BY THE MICROELECTRONIC ENGINEERING DEPARTMENT AT RIT

Programs	**Requirements (quarter credits)**	**Year of Introduction**
BS (Microelectronic Engineering)	196 credits + 15 months of Co-op	1982
ME (Microelectronics Manufacturing Engineering (also offered Online)	45 credits include 5 credits for Internship	1987
MS (Microelectronic Engineering)	45 credits include 9 credits of thesis	1995
PhD Microsystems Engineering	92 credits of graduate course work, 24 credits in dissertation research.	2002
BS–MS (Microelectronic and Materials Science and Engineering)	225 credits with 9 credits of thesis	2003
Minor Semiconductor Processing	20 credits of semiconductor processing courses	2005

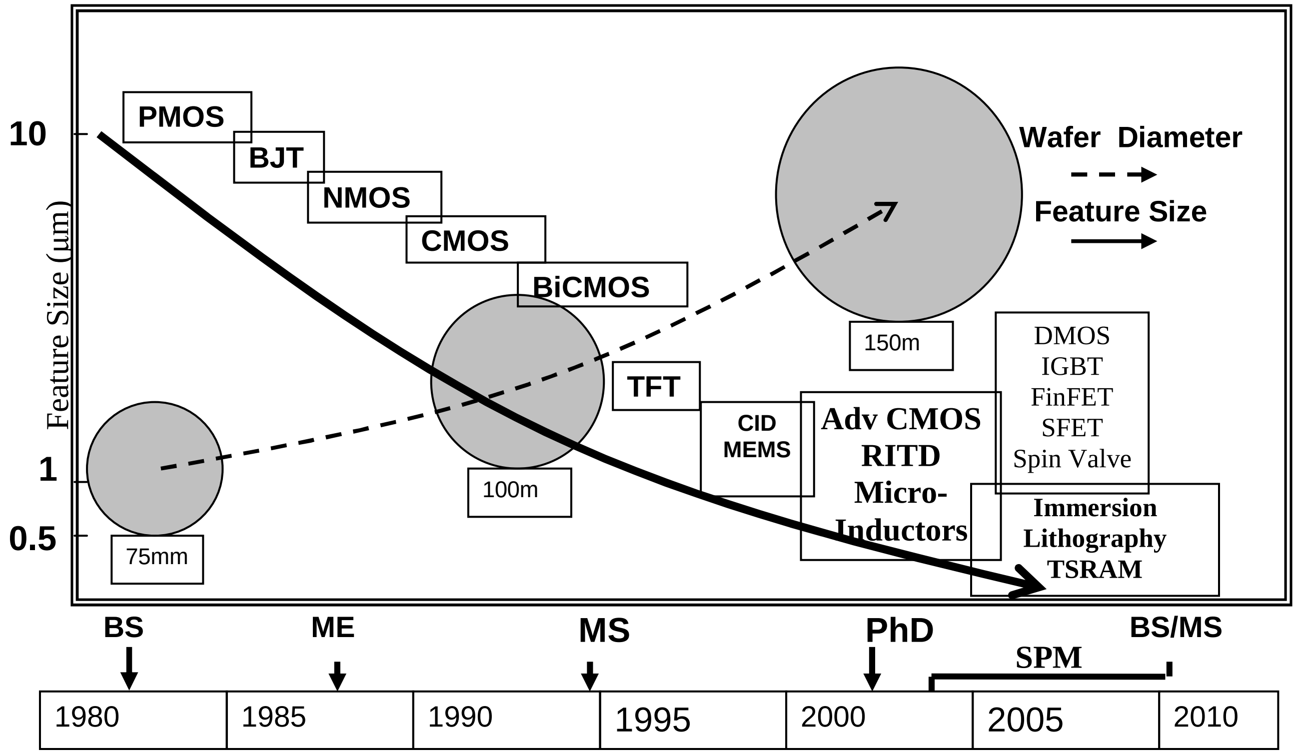

Figure 1. Curriculum and technology evolution over the last 25 years in Microelectronic Engineering program at RIT. [6].

New Undergraduate Minor Program in Semiconductor Processing for Non-μE Students

We have developed a five course minor in microelectronics for non-μE science and engineering students who desire exposure and experience to the exciting world of nanotechnology. We believe that this minor may do more to increase the number students with engineering experience at RIT by utilizing the large number already enrolled in the College of Science programs, as opposed to separate recruitment strategies geared solely toward engineering. This program is designed to provide basic knowledge to students from other engineering and science disciplines interested in a career in the semiconductor industry that include design, manufacture, equipment, chemicals, and software sectors. The minor consists of five courses: three core and two electives as given in Table II. Currently students from a variety of majors are enrolled in this minor program. These include students from electrical engineering, software engineering, physics, imaging science and multidisciplinary studies.

The formulation of flexible curriculum has also enabled μE students to take minor programs in other disciplines. Since the establishment of this new curriculum several students are enrolled in minor programs in mathematics and statistics, physics, business, economics, and psychology.

TABLE II: SEMICONDUCTOR PROCESSING MINOR (SPM) CURRICULUM	
Level	**Courses**
Freshmen Level	Intro to Microlithography
Sophomore Level	IC Technology
Senior Level	Thin Film Processes
Two Electives	Process Integration
	CMOS Processing Lab
	Microlithography Materials & Processes
	Process and Device Modeling
	Nanoscale CMOS
	Microelectronics Manufacturing
	Microelectromechanical Systems

High School Teachers Forum

We have developed and conducted a K-12 Outreach Teachers Forum to focus on the work force needs of the US high tech industry. A two day laboratory based activities sessions were conducted with 12 science teachers from different schools. The goal is to develop active and engaging learning opportunities for K-12 students. Resources needed for K-12 teachers to bring the world of microelectronics and nanotechnology to their classrooms is discussed. Various sessions conducted are listed in Table III.

Table III: 2 Day K-12 Teachers Forum at RIT
Session I
Origin of nanoelectronics and the promise of nanotechnology
Fundamentals of semiconductor devices
Electronics laboratory experience: electrical measurements on basic devices
Materials science of nanofabrication: Overview of unit integrated circuit fabrication processes
Microscopy and lithography lab experience
Session II
Snapshot of today's high technology fields
Emerging technologies (Technology roadmap, MEMs, nanotechnology)
Forum for high school teachers: where and how could, today's high school curriculum prepare students for these hi-tech careers?
Academic programs and research, discussion with undergraduate and graduate students.
Forum between faculty and teachers; opportunities, gaps, challenges, actions

Microelectronic Engineering and Service Learning

Service-Learning (SL) is an educational method and practice of teaching by which participants learn and develop through active participation in services that meet the needs of the community. An extensive study was carried out on the SL initiatives at various universities. To implement SL one may utilize an array of methods specific to the discipline involved- the key is identifying need and creating a program with solid communication between its constituents. SL and microelectronic engineering is difficult, but not impossible. For example mechanical and electrical engineering is much more dynamic from a community need-to-product standpoint than microelectronic engineering. The products of mechanical and electrical engineers are tangible- you can build something great in a garage. This is quite the opposite when considering microelectronic engineering a topic that is seldom known to the outside observer. Unlike other disciplines, however microelectronic engineers are in a unique position to make an impact on the High School and Junior High School levels where the Ipods, cell phones, PDAs, and hand held cameras rein supreme. Microelectronic engineers are capable of bringing a wealth of information, knowledge, and understanding of topics appealing to the potential biologists, chemists, mathematicians, and physicists. A unique co-op assignment has been crafted wherein a microelectronic co-op student will work with a K-12 science teacher in developing new laboratory experiments that fit within the instructor's curriculum.

Future Directions

The students entering into the BS program in 2007 will graduate in 2012, - projected to be sub 45nm CMOS node. The end of conventional CMOS is in sight. We have to prepare students for understanding manufacturing issues at sub 45 nm nodes and 450mm wafer diameters, learning new concepts such as quantum confinement, subthreshold logic, 3D integration, spintronics, self assembly and quantum computing. In addition, microelectronics is spinning off to new frontiers for which educational curricula need to respond [9].

A new *Nanoengineering* concentration within the BS program in Microelectronic Engineering is under development. This concentration will consist of a set of courses dedicated to the fundamentals and applications of materials/devices engineered at nanometer scales. To support this initiative, a nanocharacterization laboratory – Advanced Materials Characterization Laboratory (AMCLab) has been created. AMCLab has equipment for scanning probe microscopy (multiple modes), powder and high-resolution x-ray diffraction (XRD), micro- and nano- indentation, and quantitative imaging. In the AMCLab, advanced undergraduate and graduate students obtain training in the use of experimental tools to image and probe surface properties at micro- and nano scales. Multiple modes of SPM equipment include scanning tunneling microscopy, contact and tapping mode atomic force microscopy, electric force microscopy, magnetic force microscopy, lateral force microscopy, and force modulation spectroscopy.

The HRXRD equipment, in addition to conventional powder diffractometry techniques, permits high resolution XRD using double- and triple- axis measurements, x-ray reflectometery, and is equipped with a two-dimensional detector and a high-temperature stage to study phase transformations, texture and crystal-size effects. A new course on nanocharacterization has been developed to educate students in nanometrology [10].

Summary

The curricula in microelectronic engineering at Rochester Institute of Technology have been evolving focused on the educational and research needs of the semiconductor industry. These programs accompany a state of the art Semiconductor and Microsystems Fabrication Laboratory, and a newly equipped Advanced Materials Laboratory for nanocharacterization. The program has made continuous enhancements in courses contents, levels and laboratory capabilities. We have led our program to the next level by introducing wider educational opportunities into the curriculum. A new experimental service learning co-op program has been envisioned to complement our K-12 outreach. A forum with high school science teachers on microelectronics and nanotechnology has been constituted.

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