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Materials Science and Engineering Education for Microelectronics and Nanotechnology

Abstract

New and diverse materials are being engineered and integrated into micro/nano devices and systems. This has been made possible by interdisciplinary research amongst people from a wide range of engineering and science disciplines. In the field of nanotechnology the boundaries between disciplines fade and new curricula designs become imperative. A novel dual degree program of Bachelor of Science in Microelectronic Engineering and Master of Science in Materials Science and Engineering has been developed and instituted at Rochester Institute of Technology (RIT). It is interdisciplinary between College of Engineering and College of Science. This five-year program consists of completion of 225 quarter credits that include a minimum of 12 months of co-op experience, 36 graduate course credits and 9 credits of research. The first graduates of this program graduated in 2005 and the enrollment is showing a steady increase. The program has received outstanding response from the semiconductor industry. Graduates with hands-on education in semiconductor devices, processes, and materials synthesis and analysis and co-op experience in industry are very attractive for employers in this field.

Introduction

Today’s industrial growth is largely dependent on understanding of the nature of materials, and is driven, in part, by the development of new materials that are engineered at the micrometer and nanometer scales. Semiconductor and electrical engineering technologies have steadily evolved over the past four decades to meet the increasing needs of the information age through the development of advanced device structures, circuit design methodologies, microfabrication techniques, and novel materials and processes. Mainstream semiconductor technology development has spun off new fields of research such as nanotechnology, micro-electro-mechanical devices and systems, photonic devices, bio-chemical devices and systems on a chip. The objective of this unique educational curriculum is the development of a multidisciplinary work force to address the challenges of integrating new and diverse materials into micro/nano devices and systems. For expanding applications, it is essential to connect them to the macroscopic world by routing through well developed silicon electronics. Some of the most important issues are material patterning, process development, stability and reliability. These issues require fundamental materials understanding and identification of process parameters for a variety of technologies to facilitate integration of MEMS, ceramics, magnetics, spintronics, molecular, polymeric and biomaterials with silicon electronics. The conventional top down methodology for miniaturization has advanced to nanoscales, while bottom up and self assembling methodologies at molecular and atomistic scales are evolving.

The integrated circuit technology began with using essentially a few materials – doped silicon, silicon dioxide and aluminum in 1960s. Subsequently more and more materials have been integrated following extensive materials research. Figure 1 shows that today’s semiconductor technology spans a much larger part of the periodic table. The elements manifest their integration through syntheses of materials with desired properties onto the chips. Various
processes and characterization techniques are being employed that need to be included in curricula designed to prepare workforce for seeking careers in the field of emerging technology of microelectronics, MEMs and nanotechnology.

Figure 1. More and more element constituents in materials employed in modern semiconductor technology over the last two-three decades.

The BS Program in Microelectronic Engineering

The five-year BS program in Microelectronic Engineering began in 1982, consists of 196 quarter credit hour coursework with 15 months of mandatory co-op experience integrated throughout the five years. Students are given the ‘cleanroom’ experience right from the first quarter they join the program. The program combines essential electrical engineering curriculum combined with optics and lithography, semiconductor processing and manufacturing. The program is ABET accredited and has received full accreditation in 2004 under the new ABET Engineering Criterion EC 2000. At the present time, 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, deep UV and 1-line wafer steppers, electron beam mask writer, and device design, modeling and test laboratories. The program enjoys a
strong support from the semiconductor industry through the industrial affiliate program. Industry support has been extremely valuable, perhaps one of the most critical factors for sustaining this program. The curriculum combines subjects such as semiconductor device physics, circuits and electronics, microlithography, integrated circuit (IC) processing and thin film processes.

The program has several courses from second through fifth year that include important materials science and engineering content. These are

- Solid crystalline structures
- Oxidation
- Diffusion
- Ion Implantation
- Physical Vapor Deposition
- Chemical Vapor Deposition
- Plasma processes
- Electrochemistry
- Chemical Mechanical Planarization
- Materials Analysis
- Optical properties and lithography

The program encompasses capstone senior design project that involves design and development of integrated device, component, process or capability at RIT. Students publish their senior project papers in proceedings published each year. The trend over the last several years shows that ~30-50% of senior projects entail materials process development. In addition, students get opportunities during their co-op experience to engage in materials/process development projects.

Further graduate coursework in materials science and engineering will provide deeper understanding of materials engineering fundamentals critically needed for pursuing research in materials for devices.

**The MS Program in Materials Science and Engineering**

The Materials Science and Engineering program is a joint offering of the College of Science and the College of Engineering at RIT. It involves active participation by the Departments of Chemistry, Physics, Microelectronic Engineering, Imaging Science, Electrical Engineering, and Mechanical Engineering, thereby providing an opportunity to design an interdisciplinary program directly responsive to the student's interests and needs. The MS program in Materials Science and Engineering consists of 5 core courses dealing with theoretical, experimental and analytical aspects of materials in addition to a variety of elective courses (Table I).
## Table I: The MS Program in Materials Science and Engineering

<table>
<thead>
<tr>
<th>MS Program Core Courses</th>
<th>MS Program Elective Courses</th>
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<tbody>
<tr>
<td>Introduction to Material Science</td>
<td>Microscopy &amp; Spectroscopy</td>
</tr>
<tr>
<td>Introduction to Polymer Science</td>
<td>Thin Film Processes</td>
</tr>
<tr>
<td>Solid State Science</td>
<td>Microlithography Materials and Processes</td>
</tr>
<tr>
<td>Introduction to Theoretical Methods</td>
<td>Glass Science</td>
</tr>
<tr>
<td>Experimental Techniques I</td>
<td>Material Degradation: Corrosion</td>
</tr>
<tr>
<td>Experimental Techniques II</td>
<td>Organic Polymers</td>
</tr>
<tr>
<td>Seminar</td>
<td>Physical Chemistry of Polymers</td>
</tr>
<tr>
<td>Thesis</td>
<td>Polymer Processing</td>
</tr>
<tr>
<td></td>
<td>Optical Properties of Materials</td>
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<tr>
<td></td>
<td>Magnetic Properties of Materials</td>
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<td></td>
<td>Advanced optics</td>
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<td></td>
<td>Amorphous and Semicrystalline Semiconductors</td>
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<tr>
<td></td>
<td>Nuclear Science and Engineering</td>
</tr>
<tr>
<td></td>
<td>Plasma Science</td>
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<tr>
<td></td>
<td>Physics &amp; Chemistry of IC processing</td>
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</tbody>
</table>

### The Combined Curriculum

A combined BS (Microelectronic Engineering)-MS (Materials Science and Engineering) program constructed out of existing BS and MS programs was proposed in 2002, and was approved by the NY State in 2003. This five-year program consists of completion of 225 quarter credits that include a minimum of 12 months of co-op experience, 36 graduate course credits and 9 credits of research. The BS program in Microelectronic Engineering consists of 196 quarter credit hours with two professional electives. A maximum of four graduate level courses (16 quarter credits) taken for the BS program may count towards the MS program. The program mandates 9 quarter credits of thesis supervised by a joint thesis committee. Students are advised to develop thesis from their senior project work.

![Figure 2. Credit distribution in the combined BS-MS program](image)
It is designed as an integrated dual degree program where students begin taking MS courses in their fourth year. One Co-op block is substituted by graduate course work. The program enables qualified students enrolled in the BS Microelectronic Engineering program to obtain an additional MS degree in Material Science and Engineering in five years with an additional summer quarter to conclude thesis work (Table II).

<table>
<thead>
<tr>
<th>Year</th>
<th>Fall</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>School</td>
<td>School</td>
<td>School</td>
<td>Vacation</td>
</tr>
<tr>
<td>2</td>
<td>School</td>
<td>School</td>
<td>School</td>
<td>Co-op</td>
</tr>
<tr>
<td>3</td>
<td>Co-op</td>
<td>School</td>
<td>School</td>
<td>Co-op</td>
</tr>
<tr>
<td>4</td>
<td>Co-op</td>
<td>Micro/MSE</td>
<td>Micro/MSE</td>
<td>Micro</td>
</tr>
<tr>
<td>5</td>
<td>Micro/MSE</td>
<td>Micro/MSE</td>
<td>Micro/MSE</td>
<td>Thesis</td>
</tr>
</tbody>
</table>

The program provides appreciation and attempts to equip the students with materials science knowledge for seeking graduate research and career in emerging fields on MEMs and nanotechnology spinning off from semiconductor technology.

Associated Laboratory Facilities

The program is supported with a state-of-the-art IC fabrication facility and an Advanced Materials Characterization Laboratory (AMCLab). The IC fabrication facility consists of a complete CMOS line having e-beam mask making, deep UV and I line photolithography, implant, CVD, PVD, plasma and CMP capabilities in addition to electrical test and metrology. Undergraduate students receive practical experience of design and fabrication of semiconductor devices throughout the curriculum.

AMCLab has equipment for scanning probe microscopy (multiple modes), powder and high-resolution x-ray diffraction (HRXRD), 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 diffraction techniques, permits high resolution XRD using double- and triple-axis measurements, x-ray reflectometry, and is equipped with a two-dimensional detector and a high-temperature stage to study phase transformations, texture and crystal-size effects.

Results

It is an intensive and challenging program. Two students (out of 25 Microelectronic Engineering students) enrolled in this program in its debut. Texas Instruments supported the first student to
pursue research on aluminum alloy films for micro mirror applications. The student investigated optical visible reflection coefficient of aluminum films alloyed with chromium, copper and titanium, and developed universal dielectric function model. He was subsequently hired by Texas Instruments on graduation. The second student investigated and developed nickel monosilicide process at RIT and joined IBM on graduation. Success of these students prompted interest and enrollment doubled in 2005. The assessment of the program is carried out through a survey collected from students after their placement. Table III provides a list of thesis areas and placement of recent graduates.

<table>
<thead>
<tr>
<th>Year</th>
<th>Thesis Topic</th>
<th>Placement</th>
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<tbody>
<tr>
<td>2005</td>
<td>Aluminum alloy films for Micro reflective apps</td>
<td>Texas Instruments</td>
</tr>
<tr>
<td></td>
<td>Development of nickel monosilicide process</td>
<td>IBM</td>
</tr>
<tr>
<td>2006</td>
<td>Self aligned metal gate structures</td>
<td>AMD</td>
</tr>
<tr>
<td></td>
<td>Low temperature dopant activation</td>
<td>IBM</td>
</tr>
<tr>
<td></td>
<td>Hafnium oxide for gate dielectric</td>
<td>IBM</td>
</tr>
</tbody>
</table>

The students extensively use the IC fabrication and materials synthesis and analytical facilities at RIT. A new course entitled “Micro- and Nano- Characterization of Materials and Surfaces” has been developed to meet the needs of this program.

A survey has been designed to assess the program and its outcomes. It seeks input from graduates within 1-2 years from their job placement. This survey is available online and responses are being collected. The results will be presented at the conference.

In conclusion, an innovative joint program has been established at RIT for developing workforce for meeting challenges of novel materials integration in micro/nano electronics, MEMs and nanotechnology. The program consists of formidable co-op and laboratory experience. This combined program in Microelectronic and Materials Science and Engineering has received very encouraging response from students and employers.

Acknowledgement

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References


