

## **2007: INDIVIDUAL CAPSTONE DESIGN PROJECTS IN THE MULTIDISCIPLINARY FIELDS OF MICROELECTRONIC ENGINEERING, MEMS AND NANOTECHNOLOGY**

### **Santosh Kurinec, Rochester Institute of Technology**

Santosh K. Kurinec is Professor and the Department Head of Microelectronic Engineering at Rochester Institute of Technology (RIT). She has extensive experience on electronic materials and their integration in semiconductor devices. Her current research involves magnetic tunnel devices and novel materials for dielectrics and interconnects.

### **Michael Jackson, Rochester Institute of Technology**

Michael A. Jackson received his PhD from the State University of New York, Buffalo and is an Associate Professor of Microelectronic Engineering at RIT. His research interests include metrology, yield and reliability, thin films and chemical mechanical planarization.

### **Sean Rommel, Rochester Institute of Technology**

Sean L. Rommel, PhD from the University of Delaware is an Assistant Professor of Microelectronic Engineering program at RIT. His research interests include design and fabrication of resonant tunnel diode based devices and circuits. He has been the senior project faculty in recent years.

### **Karl Hirschman, Rochester Institute of Technology**

Karl D. Hirschman is the Micron Professor of Microelectronic Engineering, and the Director of the Semiconductor & Microsystems Fabrication Laboratory at the Rochester Institute of Technology. He teaches courses on process technology, and process and device simulation and modeling. His active research area is focused on thin-film electronic devices and process modeling.

### **Lynn Fuller, Rochester Institute of Technology**

Lynn F. Fuller is the founder of Microelectronic Engineering program at Rochester Institute of Technology and served as the Department Head from 1982-2000. He is a Fellow of the IEEE. He has received the RIT Outstanding Alumni Award, 1990 and RIT Eisenhart Outstanding Teacher Award, 2007. His research is focused on Microsystems, CMOS manufacturing and MEMS.

# **Individual Capstone Design Projects in the Multidisciplinary Fields of Microelectronic Engineering, MEMS and Nanotechnology**

## **Abstract**

The capstone senior design projects in the BS curriculum in Microelectronic Engineering at Rochester Institute of Technology consist of individual projects since the inception of the program twenty five years ago in 1982. This model has served the students and the program extremely well as the senior projects have resulted in continuous laboratory development while proving a powerful tool for program outcome assessment. Each year the projects become more advanced and challenging. During the early years the capstone project course was a one four credit course. As the semiconductor process technology became more advanced, the capstone experience was spread over two academic quarters consisting of two courses - Senior Design Project I and II. During the Senior Design Project I, each student develops and defends a proposal describing project goals, a detailed research plan with experimental design, a time table, and resources needed, and anticipated results. The students are also required to address ethical and societal impact of their project work. Typically the topics have included integrated circuit devices and components, process developments for advanced structures, MEMs, sensors, micro/nanolithography, plasma deposition and etching, and PVD or CVD processes. In addition, projects include simulations, modeling, test and characterizations. Even though projects are individual, students work with *self assembled* teams of faculty, engineers, technicians, graduate and undergraduate students and sometimes industry personnel.

## **Introduction**

The purpose of the Capstone Experience is to give students the opportunity to demonstrate their ability to organize and synthesize knowledge as developed throughout their academic program. According to the ABET EC 2000 criteria, *Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier coursework and incorporating engineering standards and realistic constraints*. This course also serves as a powerful tool for program outcome assessment<sup>1</sup>.

## **The BS Program in Microelectronic Engineering**

The Microelectronic Engineering program at Rochester Institute of Technology (RIT) is ABET accredited Bachelor of Science program granting a degree in Microelectronic Engineering. The most recent ABET accreditation was received under the EC 2000 criteria in the year 2005. The program is designed to prepare students for employment in the semiconductor industry, in associated industries and government agencies. The curriculum also prepares students for graduate studies in related disciplines. The program consists on 196 quarter credits and is completed in five years with fifteen months of mandatory cooperative experience.

The program started in 1982 to drive the PC revolution that had just begun. Today the program supports a complete 4 and 6 inch CMOS line equipped with diffusion, ion implantation, plasma and CVD processes, chemical mechanical planarization, electron microscopes and device design, modeling and test laboratories. The main portion of the facility is 10,000 sq. ft. of class 1000 cleanroom with a bay and chase configuration. Additional laboratory space includes a class 100/10 MEBES E-beam Laboratory (established by Perkin-Elmer), an Excimer Laser Laboratory (established by the Keck Foundation), a surface analysis laboratory, a chemical-mechanical planarization laboratory, and an electrical characterization laboratory<sup>2</sup>.

## **Program Educational Objectives**

In order to meet the needs of all constituents (semiconductor industry, students, graduate schools and faculty) and prospective employers in accordance with the program mission, the educational objectives of the Microelectronic Engineering program are to produce graduates who have the following skills or characteristics<sup>3</sup>:

- *A Firm Foundation in the Fundamentals* – A sound knowledge of the scientific principles involved in the operation, design, and fabrication of integrated circuits.
- *A Knowledge of Relevant Technologies* – A comprehensive understanding of integrated circuit process integration and manufacturing, including microlithography and the application of engineering principles to the design and development of current and future semiconductor technologies.
- *A Professional Approach to Problem Solving* – An ability to use one’s analytical, academic, and communication skills effectively, with special emphasis on working in teams.
- *An Enthusiasm for Learning* – An interest in continuous improvement of skills throughout one’s career by learning about emerging technologies and adapting to and accepting change. A desire to achieve leadership positions in industry or academia.
- *A Breadth of Knowledge* – A knowledge of the “larger picture” of engineering, including the multidisciplinary nature of microelectronic engineering, as well as the broad social, ethical, safety, and environmental issues within which engineering is practiced.

## **Program Outcomes**

The program outcomes for the Microelectronic Engineering program are determined to be:

1. *Understand* the fundamental scientific principles governing solid state devices and their integration into modern integrated circuits.
2. *Design and conduct* a sequence of processing steps to fabricate a solid state device to meet a set of geometric, electrical, and/or processing parameters.
3. *Acquire and analyze* experimental electrical data from a solid-state device to extract performance parameters for comparison to modeling parameters used in the device design
4. *Conceive and conduct* a designed experiment to characterize and/or improve a process utilized in IC fabrication.
5. *Communicate* the results of an in-depth engineering research experience using techniques appropriate for oral, poster, and paper presentations at technical conferences.
6. *Enter the job market or graduate school* with the required engineering co-op experience.

7. *Understand the relevance* of a process or device, either proposed, past or existing, to current manufacturing practices.
8. *Understand, characterize, or modify* current lithographic materials, processes, and systems to meet imaging and/or device patterning requirements.
9. *Appreciate the multidisciplinary nature* of the field and the inherent trade-off between breadth and depth of knowledge.

### Capstone Senior Design Experience

At the beginning of the BS program, the capstone course was known as Seminar Research and was held during graduating spring quarter. Subsequently, the course evolved into a sequence of two courses as shown in Table I. With the advancement of laboratory processes and capabilities, students were involved in more demanding capstone experience. In addition, ABET criteria required capstone course to include design, societal impact, and team work.

<b>Table I. Evolution of Capstone Experience in the BS Program in Microelectronic Engineering</b>				
<b>Quarter Initiated</b>	<b>Capstone Course Number /Title</b>	<b>Quarter Credits</b>	<b>Offering</b>	<b>Requirements</b>
19843 4 credits	0305-660 Seminar Research	4	Spring quarter of 5 <sup>th</sup> year	Conference Proposal, Paper, Presentation
20001 4 credits	0305-680 Seminar Research I	2	Fall and Winter quarter of 5 <sup>th</sup> year	Proposal
	0305-690 Seminar Research II	2	Spring quarter of 5 <sup>th</sup> year	Conference Presentation, Paper
20051 6 credits	0305-681 Senior Design Project I	4	Fall and Winter quarter of 5 <sup>th</sup> Year	Detailed Proposal with Designs, In-class Presentation
	0305-691 Senior Design Project I	2	Spring quarter of 5 <sup>th</sup> year	Conference Presentation, Paper

At present time, the BS program requires 6 credit capstone sequence of two courses – Senior Design Project I and II as described below.

One faculty is assigned as the designated instructor for each of the courses. However, all faculty members participate in advising the students on projects that fall under their field of research and instruction. The two-course sequence consists of:

### Proposal Submission

Students carryout literature search, discuss with faculty and/or with their co-op managers to come up with ideas for their projects. The proposals are to be submitted by each student that describes objective, detailed research plan with experimental design, resources needed, anticipated results as well as ethical and societal impact. If the proposal involves specific mask designs, they are required to submit mask orders for electron beam mask writing. Students are made to appreciate constraints of time, resources, and safety. For example, if a new chemical is to be used, they would need to refer to MSDS sheets (Materials Safety and Data Sheet) for addressing safety and contaminations issues. At the end of the quarter, students make presentations to defend their proposals in front of faculty and peers.

### Experimentation

After obtaining approval of their proposals, students begin working on and submit weekly reports on their progress. They find collaborators, obtain tool certifications, and request for wafers and supplies. The students often develop alliances (self assembly of complementary strengths) of sharing tool runs, watching each others experiments when in classes. Their sensitivity to ethics is apparent when they acknowledge the help they receive in their presentations.

### Abstract, Poster and Oral Presentation

On the day of the conference, a book of abstract is released that consists of student project abstracts. Students make posters (44"x36") using PowerPoint and print for display. The poster contains project objective, plan, results and discussion. Poster session is displayed on throughout the conference and students stand by their poster during the session breaks. In oral presentations, students are guided how to make effective presentation in the allotted time. Students are introduced by the session chair reading their short bio and the title. Students display high level of professionalism and take a great deal of pride and sense of achievement. The entire conference is video taped and archived to be shown to future students.

### Final Paper

At the end of the completion of their projects and conference, students submit their final paper written in a standard prescribed IEEE format. These papers are then compiled in the Annual Journal of Microelectronic Research published and released on the day of graduation each year. The papers are made available online. Typically 25 senior projects are presented each year.

### **Design of Experiments Course**

The Design of Experiments (DOE) course allows for development of the student's understanding of relationships that provides methods for judgment about various facets of their environment. The course explores how statistics, process capability and experimental design (full factorial, fractional factorial, Box-Behnken, and central composite) can be used in conjunction with analysis of variance, regression, and response surface methodology to build predictive models

for outcomes as a function of inputs. The DOE course was first introduced in the curriculum in 1994 and was placed in the 4<sup>th</sup> year of the five year BS program. As the laboratory developed and more students required the knowledge of DOE for their co-op, the course was moved to the second year in 2003 with the advice of the Advisory Board. The DOE course feeds very well to the senior projects as most of the process development uses optimization through the use of DOE.

### **Grading Senior Projects**

The assigned instructor submits the grades according to the course grading policy. In the Senior Design Project II, entire faculty of Microelectronic Engineering and invited industry representatives at the conference are requested to evaluate posters and oral presentations. These evaluations are included in deciding the final grades. In addition, these evaluations help in providing a valuable feedback and assessment tool of the program outcomes.

### **Senior Design Projects Data Base**

The department maintains a library of all the senior projects papers and video tapes of presentations. A data base is maintained and students can search a particular topic and access the papers. In some cases, lab notebooks are also stored. Full papers and posters of senior projects can be accessed from the department web site<sup>3</sup>. Figure 1 shows a photograph showing that the department publishes a book of abstracts, journal of proceedings and video production of oral presentations and online availability of papers and posters.

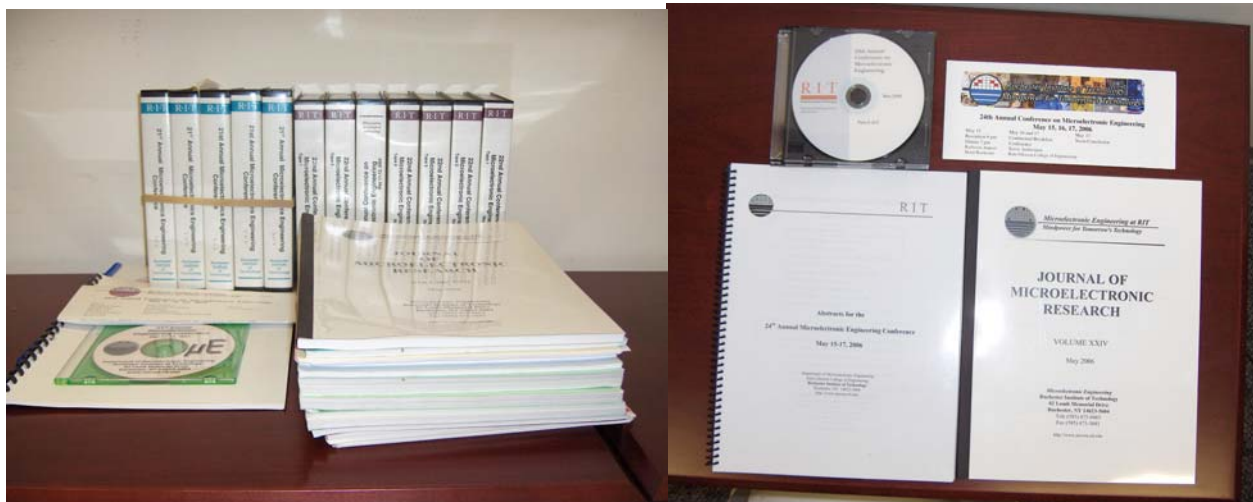


Fig.1. Photograph showing senior project material produced and made available for open dissemination.

### **Laboratory and Research Infrastructure Development**

The senior design projects have been instrumental in developing laboratory infrastructure since the inception of the BS program. It was only in 1995, that the first Master of Science program

was started and subsequently in 2002, PhD program in Microsystems Engineering evolved. Figure 2 and 3 illustrate the significance and contributions of senior projects in curriculum laboratory development and graduate research.

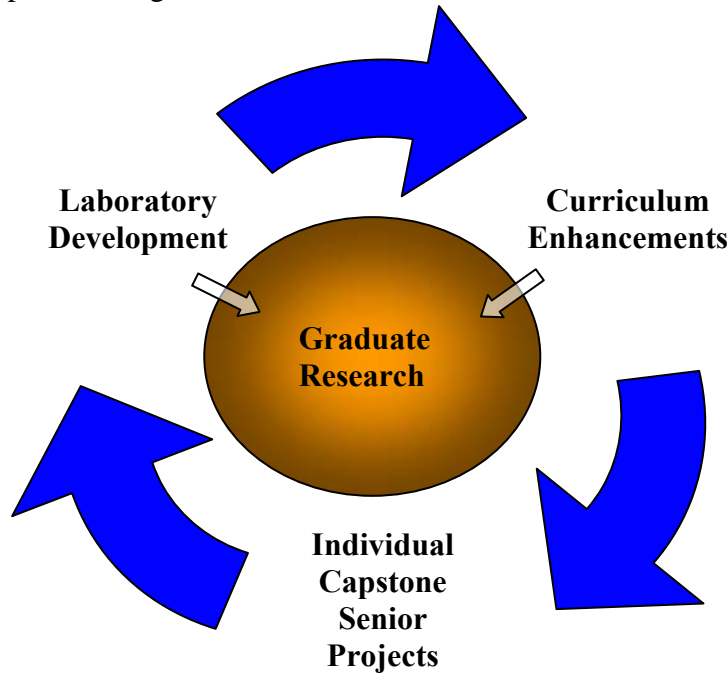


Fig. 2. Role of senior design projects in strengthening the undergraduate and graduate programs of Microelectronic Engineering at Rochester Institute of Technology (RIT)

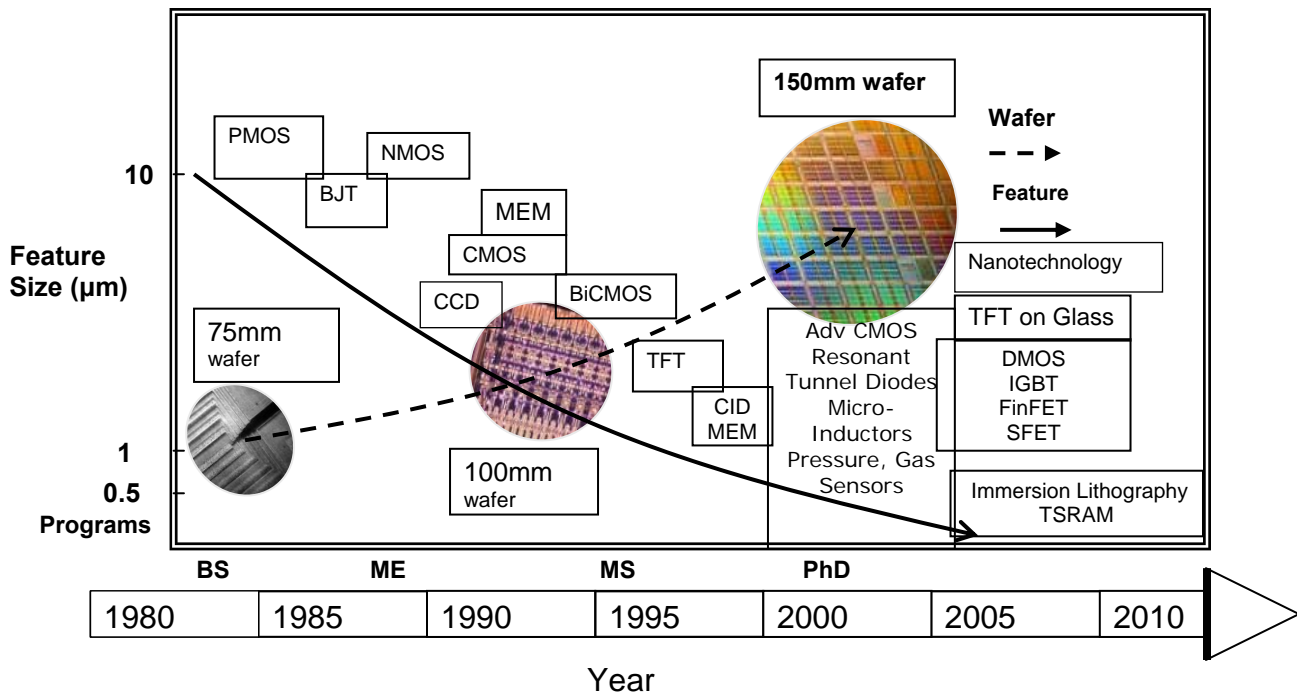


Fig. 3. Technology development through senior design projects at RIT.

## Program Outcome Assessment

The senior projects are evaluated by the faculty and invited industrial guests. The evaluation criteria are provided to the evaluators on the day of the conference. These criteria include application of math, science and engineering, engineering design, contemporary issues, societal impact, poster and oral presentation skills. The capstone courses are mapped against the program outcomes as shown in Table II. The evaluations by industry representatives and faculty provide excellent metrics for program assessment.

Courses		MicroE Program Outcomes								
Program Outcomes →		1	2	3	4	5	6	7	8	9
0305-681	Senior Design Project I									
0305-691	Seminar Design Project II									
		<b>High</b>			<b>Medium</b>			<b>Low</b>		

The projects range in topics from device design, fabrication, process development, simulations and test. The faculty monitors the distribution in these categories. If the number of projects in a category is less than desired, a weakness is identified and steps are taken to improve.

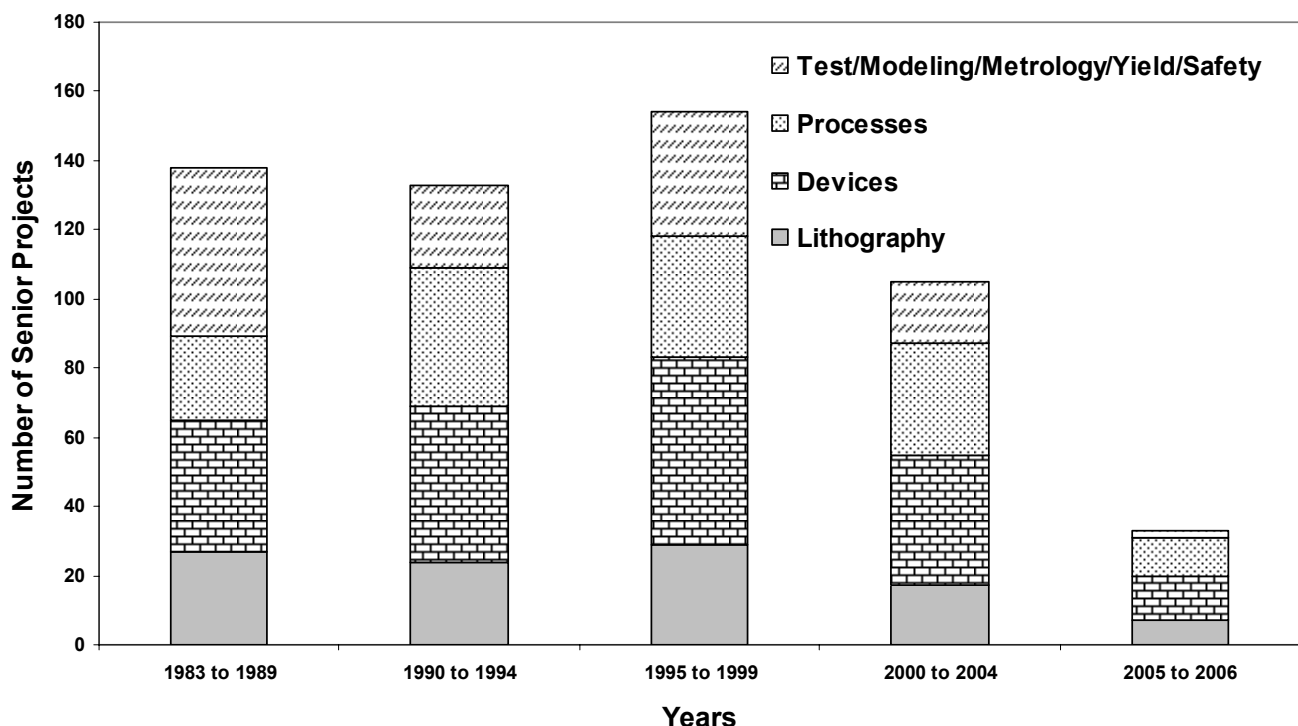


Fig. 4. Number of senior projects in each category in the last 25 years.

Figure 4 shows the number of senior projects in each category – lithography, devices, processes and others in five year period over the last 25 years. A fairly uniform distribution among various categories is observed.

### **Example Senior Project Topics in Microelectronics, MEMS and Nanotechnology**

Design and fabrication of microelectronic devices, components, circuits and systems are the foundations of our program. As the integrated circuit techniques are being applied to micro electromechanical devices, MEM based topics began to emerge. The first MEM project was carried out in 1990. Since then, number of MEMs projects increased and this set the groundwork for the Microsystems Engineering program at RIT. Nanotechnology based projects is a recent development. Capabilities are being created to undertake nanotechnology project that include nano patterning and nano characterization facilities. Given below are titles of some of the recent microelectronics, MEMs and nanotechnology projects.

#### **Microelectronics**

- Design and fabrication of 0.5  $\mu\text{m}$  N-Channel MOS transistors
- Metal source/drain Schottky Field Effect Transistors (MSD SFETs): Proof of concept.
- Design and fabrication of tri-gated FinFET on SOI
- Capacitance voltage analysis of high-k dielectric on strained silicon
- NMOS transistor design and fabrication for S-parameter extraction

#### **MEMS**

- Design and analysis of a CMOS based MEMs accelerometer
- Investigation of silicon etching effects for monolithic integration of MEMs with CMOS
- BIOMEMs wireless pressure sensor
- Microfabrication and commercialization of a polymer absorption chemical gas sensor
- Microfabrication of biocompatible stimulation arrays for cochlear implants

#### **Nanolithography and Nanotechnology**

- Study of the interaction between Ultra-pure H<sub>2</sub>O and photoresist in immersion lithography at 193nm
- Printing of contact holes for the 45nm generation using immersion interference lithography
- Carbon nanotubes: CVD reactor design and growth of multi- walled carbon nanotube
- Design and fabrication of giant magnetoresistance (GMR) spin valve structures
- Electrophoretic deposition of Ni ferrite nanoparticles for on chip magnetics.

### **Multidisciplinary versus Individual Projects**

As more and more emphasis is being placed on ‘multidisciplinary’ capstone projects, the department deliberated extensively with the Advisory Board from time to time about the

implications. It was concluded that the capstone model of our program is our strength, that it provides leadership qualities to the students with a sense of accountability and achievement. The students develop teams while working on a multidisciplinary topic. While we rely on our 15 months of required co-op experience to provide team based experiences, the department welcomes its students to work on multidisciplinary teams from other departments on subjects where they can make significant contributions for professional elective credits. Co-op experience plays a big role in student's choice of projects. Sometimes they work on a topic that is of interest to their co-op managers.

## **Conclusions**

In conclusion, the individual capstone senior projects provide a major design experience to Microelectronic Engineering students at RIT based on the knowledge and skills acquired in earlier coursework and incorporating engineering standards with realistic constraints. The capstone senior projects play a critical vital role in continuously enhancing laboratory/process development in the student run integrated circuit and MEMs fabrication facility. Many of the senior projects have resulted in seeding graduate research leading to external funding and publications. This course sequence also serves as a powerful tool for program outcome assessment.

## **Acknowledgments**

The participation of the entire faculty of Microelectronic Engineering is acknowledged. Special thanks are due to Charles Gruener for providing mask fabrication and system administration support to students. The authors express their highest appreciation to the technical staff of the RIT Semiconductor and Microsystems Fabrication Laboratory for supporting senior projects. The department expresses gratitude to the Industrial Affiliates of the program for attending students' presentations at the annual conference and providing valuable feedback.

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