Challenges in the development of educational programs for MEMS technologies

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Abstract: *This paper outlines the development and continuing process of improvement of the Masters by coursework program in Microelectromechanical Systems (MEMS) at RMIT University. A survey was conducted of recent applicants to establish how applicants came to learn of the MEMS program offered at RMIT University, their previous background, work and industrial experience and the impact of the Masters program on their future career. The results and evaluation of the survey have allowed RMIT University to better focus microtechnology awareness to the appropriate groups and improve the course material and structure of the program to suit the needs of different background students.*

Keywords*: MEMS, education, postgraduate*

Introduction

The CRC for Microtechnology was established by the Federal Government of Australia to provide the vision, infrastructure, skilled people and technologies to enable enterprises in Australia to successfully compete in the international microtechnology industry (CRC for Microtechnology, 2003). As part of this vision, three Australian universities have developed three new microtechnology Masters by coursework programs to increase the skill base and knowledge of microtechnology in professional engineers and scientists. This in itself presents a formidable task for university educators. In particular, the program developed at RMIT was developed to address the educational skills and knowledge necessary for Microelectromechanical systems (Wulf, 2003). Microelectromechanical Systems (MEMS) is a new and rapidly emerging area of microtechnology. Through design and fabrication, MEMS technology combines different disciplines of engineering, physics, chemistry and biology to realise novel miniature devices such as sensors and actuators. The program is designed to introduce students to microsystems technology and to provide the necessary knowledge and skills to design, model, fabricate and interface Microsystems devices.

The Masters by coursework program at RMIT University consists of four courses, four elective courses and a minor thesis project. The four core courses are:

1. Introduction to MEMS: Principles and Design
2. Design and CAD Tools for MEMS
3. Fabrication Processes
4. Materials and Packaging for MEMS

Students are invited to select from a range of elective courses that enable them to specialise in an area of engineering such as telecommunications, optical fibre technology, microwave devices or power systems. The elective courses are intended to allow the student to integrate

MEMS technology into their field of interest. The program through course work, fabrication laboratories, computer design laboratories and research projects teaches students about MEMS technology. An emphasis in the program is placed on industrial and commercial applications of Microsystems technology. The four main objectives of the program are:

1. Design and analysis of MEMS devices and structures.
2. Development of fabrication process and sequences.
3. Integration and packaging of MEMS devices.
4. Characterisation and design verification.

The Masters program has been developed for students to integrate skills and knowledge from different fields of science and engineering. For example, electromechanical coupling of cantilever beams requires students to be able to combine both electrical and mechanical concepts. Students from Electrical Engineering and Mechanical engineering have an immediate aptitude to this program as they are familiar with electro-mechanical and thermo-mechanical interactions concepts.

Three years after the commencement of the program, a survey was conducted to assess the background knowledge and skills of students entering the program and whether, if at all, after studying the Masters program, they would consider changing their career. Further to this, the exposure of students through the media and other sources to microtechnology was surveyed, with the aim of evaluating the methods used to promote the program and technology. In summary, the aim of the survey was to establish the following about applicants:

1. How they found out about the program offered at the University and whether they knew what microtechnology was before they applied.
2. Previous background, work and industrial experience.
3. The impact of the Masters program on their future career.

The survey had a secondary purpose. In this program, students are expected to learn about other fields of science and engineering and be able to integrate ideas from different fields of science and engineering. The results from the survey were used to identify deficiencies in the skills and knowledge of students entering the program. Secondly the survey was used to determine whether the design of the program adequately met the career objectives of the students. These deficiencies were then mapped into the core courses to recognize areas of the program that could be improved or more emphasis placed during lectures and laboratories.

The survey was conducted with 25 applicants in the RMIT Masters by coursework program. The results and evaluation of the survey have allowed RMIT University to increase awareness of microtechnology to different student groups and to improve the course material and structure of the program to suit the needs of different background students.

Core Courses

Microtechnology: Introduction to principles and design

This course is designed to introduce students to the fundamental concepts of Microsystems technology, the concepts of multi-physics problems, MEMS design, MEMS fabrication and MEMS devices and applications. The three main objectives of the course are the design and analysis of MEMS devices and structures, the development of fabrication processes and sequences and to understand the issues of integration in the MEMS context. This course does not assume that students have previously studied mechanics or electrostatics, both of which are necessary to understand the fundamental principles of MEMS design. Some university MEMS programs contain mechanical courses from mechanical engineering degree programs into their postgraduate programs as a bridging course (Lin, 2001). This core course lays the fundamental principles of MEMS and these are expanded in more detail in the three other core courses. The student learns through a series of laboratories about real MEMS devices such as accelerometers and the basic principles from sensor physics and design, the signal generated by the sensor and the processing of the sensor signal. This approach demonstrates the relationship between the sensor design and the system issues. An outline of the course content is as follows:

1. Introduction to Microsystems Technology
2. Microsystems Design and Working Principles
3. Materials, Structures and Mechanical Principles
4. Fabrication and Processing
5. Integration and Packaging
6. Devices and Applications
7. Microsystems: Markets and Future Trends

Fabrication Processes

This course contains an overview of basic semiconductor physics and CMOS device structure and function, provides an overview of the total semiconductor (wafer) manufacturing process, and presents basic descriptions of the unit process modules contained within the fabrication process. The course does not assume the student has education or experience in semiconductor physics, devices, or process technology. It is appropriate for students with minimal education or experience in silicon semiconductor technology.

The course involves CMOS process simulation using IC Fab and SRIM 2000, laboratory fabrication, testing and characterization of silicon gate NMOS or CMOS devices and simple integrated circuits. Emphasis is on the practical aspects of IC fabrication, including silicon wafer cleaning, photolithography, etching, oxidation, diffusion, ion implantation, chemical vapour deposition, physical sputtering and wafer testing.

The course begins with an overview of basic silicon semiconductor physics, PN junctions, CMOS device structure and function, device leakage currents, short channel effects and hot carrier effects. Design and processing techniques that avoid these undesirable effects are identified and discussed. This is followed by a step-by-step pictorial description of process flows ranging from photolithography of starting substrates to finished wafers. The processing details at each step in the process sequences are discussed. Linkages to real world issues in the commercial manufacturing environment are explicitly identified throughout the lectures. Overviews of each unit process module employed in silicon wafer fabrication are presented. Each unit process module begins with an explanation of the theoretical principles underlying the process technology, followed by an examination of how these principles are applied in real manufacturing practice. An outline of the course content is as follows:

1. Photolithography, masking and patterning
   - Light sources and wafer exposure systems
   - Photoresists and their properties
   - Measurement techniques
2. Semiconductor oxidation and diffusion
   - Basic concepts of oxidation

- Manufacturing methods for oxide layer
- Optical and electrical characterisation of oxide layer
- Diffusion process
- Manufacturing and measurements of diffused layer

3. Process integration, testing, bonding and packaging
   - Process integration
   - Device Testing
   - Bonding
   - Device Packaging

Design and CAD Tools

MEMS fabrication processes have serious repercussions on the performance of microtechnology devices and therefore must be considered during design. Most MEMS devices and systems are made of three-dimensional structures that often involve electrostatic/electromagnetic forces, heat transmissions as well as solid/fluid interactions. Because of the inherent complex geometry, loading, and boundary conditions, the finite element method (FEM) is widely used by the MEMS industry for design analysis and simulation of such systems. Facile, integrated and comprehensive software packages are highly desired and now commercially available for MEMS designers.

This course provides the students with an overview of the finite element method, its concepts and its applicability to MEMS. It also deals with process considerations at the design stage. Through laboratory based assignments, and major project work students gain hands-on experience in the use of ANSYS and COVENTORWARE (formally known as MEMCAD) software packages to model and analyse MEMS devices for various practical applications. On completion of this course the student is expected to be proficient in the use of these packages. The main objectives of the course are to develop design concepts for practical applications, model and analyse MEMS devices and structures and to design and simulate fabrication sequences. An outline of the course content is as follows:

1. MEMS Design
2. Systems Approach to MEMS Design
3. Lumped Parameter Modelling: Matlab modelling
4. Fundamentals of Finite Element Modelling
5. ANSYS modelling Techniques
6. Fabrication Layout and Processing Diagrams
7. MEMSCAD modelling Techniques
8. Multi-physics Problems in Microsystems technology

Materials and Packaging for MEMS

Microtechnology is largely based on IC manufacturing to achieve miniaturization and integration. Current materials used in Microsystems devices such as silicon and silicon dioxide have processing and material limitations, inhibiting the development of new devices. As the manufacturing and integration of microtechnology continues to develop, new materials are needed to achieve the performance requirements of sensors and actuators. Existing IC packaging methods are not suitable for many microsystems applications. A package is required to simultaneously allow interaction with the environment and at the same time provide protection from unwanted environmental conditions. This conflicting requirement is driving new research to develop new packaging methods for microsystems applications.

This course provides students with the necessary knowledge and skills for selecting and characterising materials for microsystems applications. This course also provides an introduction to the way in which materials are classified to establish the correct language used to describe materials and their electrical, optical, thermal, magnetic, and semiconductor properties. Other non-standard materials such as polymers, ceramics and nano-materials are covered, with an emphasis on the application of these materials to MEMS devices. The current state of packaging for MEMS is reviewed and the student will engage in a packaging design for a MEMS application. A laboratory component to the course introduces students to material characterisation techniques such as SEM and EDS. The four main objectives of the course are for the student to:

1. To understand the physical and surface properties of materials and how they can be implemented in microsystems applications.
2. To understand the issues of packaging for MEMS devices and the limitations of current packaging techniques.
3. To understand the principles behind several common materials analysis techniques.
4. To be able to identify the most appropriate analysis technique to characterise a property of a material.

An outline of the course content is as follows:

1. Material and their Properties
2. Silicon Compounds and other Materials for MEMS
3. Thin Film Properties
4. Dissipation, Diffusion and Thermal Materials
5. Electronic and Magnetic Materials
6. Polymer Bio Materials
7. Ceramic and Nanomaterials
8. Material Measurement Techniques
9. EDS, SAT, SEM and TEM

Results of the survey

Background and Career

The average age of applicants was 33 years and 92% of the applicants have had on average 5 years of industry experience, with 35% having previous experience in the microelectronics industry and 23% of the applicants working in the microtechnology area. It is clear from the survey that the students of the program are not studying as a continuation from their Bachelors degree. As many of them have already worked in industry, the MEMS program must have an appeal to their future career. This is supported by the fact that 75% of applicants would consider a career change at the completion of studying the Masters program. This is believed to indicate that applicants are willing to change their career focus, and indirectly means that the applicants see MEMS as an emerging technology that will have a commercial impact with an industry ready to support these expectations.

Before the applicants learnt of the program, 88% knew of MEMS and what it means. Figure 1 is a breakdown of the way in which applicants came to learn of MEMS. Most applicants learnt of MEMS through university interactions (lecturers, friends, and laboratory involvement) and the web. As much of the emerging trends of MEMS technology is still confined to universities, this result is not surprsing as university researchers usually disseminate their research and that of others through their colleagues, friends and students.

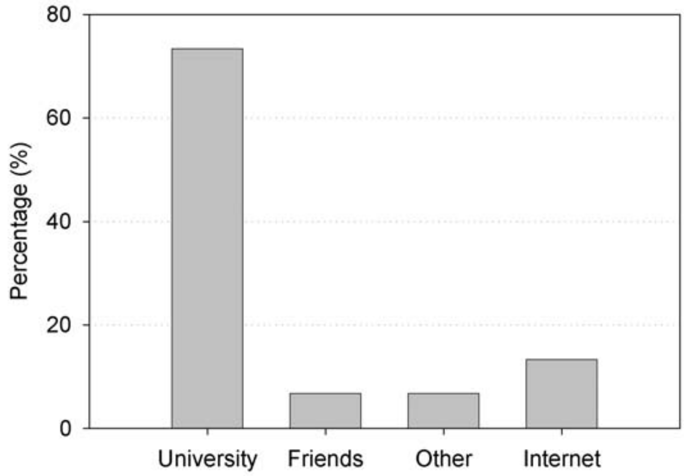

Figure 3: Different ways in which applicants learnt of MEMS, before applying to the program at RMIT

Knowledge and Skills

71% of applicants were familiar with the basic mechanical concepts that are fundamental to MEMS however only 14% had experience using finite element packages such as ANYSY to construct mechanical models. Figure 2 is a summary of the past experience applicants have had with software packages related to the microtechnology field. Clearly Matlab is a widely used and taught software package in Universities. Our approach has been to develop MEMS laboratories using Matlab to explain principles of microtechnology as a stepping stone to more standard design tools such as COVENTORWARE. In the survey, no applicants reported to have used COVENTORWARE or MEMSPro. These packages are becoming standard tools in MEMS design. The low percentage of applicants having used ANYSY and the non-exposure to COVENTORWARE or MEMSPro supports the development of the core course: Design and CAD Tools for MEMS in the Masters program.

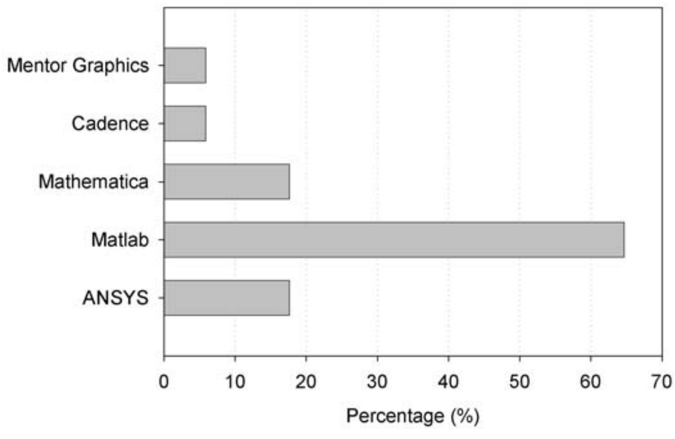

Figure 4: Experience of applicants with analytical and simulation software packages

Applicants were asked about previous science and engineering topics studied during their undergraduate degree. Figure 3 is a summary of applicant responses indicating the percentage of different topic areas studied. Table I is a breakdown of the undergraduate degrees studied by the applicants. 70.6% of applicants are either Electronic or Electrical Engineers, with a small percentage from science and mechanical engineering. This result agrees with the course structuring and student backgrounds of other international programs (Liu, 1997). Most of the applicants had studied circuit theory, magnetics and Electromagnetic Wave Theory (EM Theory) which are core topics in Electrical and Electronic Engineering undergraduate degrees. Applicants have a clear deficiency in electrostatics, with only 1 in 2 having studied the topic, and only 1 in 3 having studied fluidics at an undergraduate level. The same is true for thermal physics. These three topics, fluidics, electrostatics and thermal physics are mandatory to someone learning about MEMS. As a result, the course content that treats these three areas is being expanded and Matlab learning laboratories are being developed for these topics.

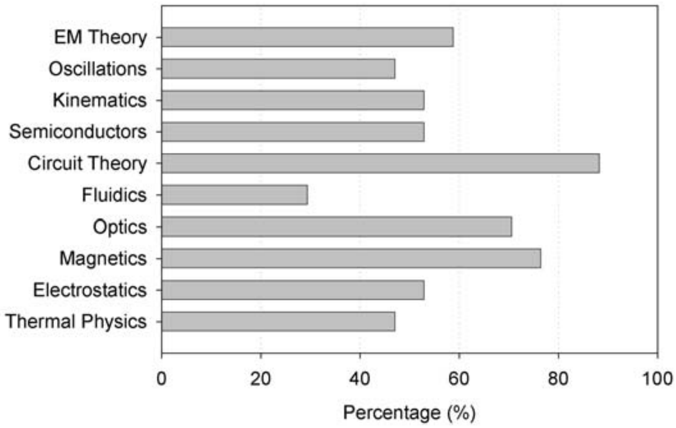

Figure 5: Undergraduate topics studied by applicants

Undergraduate Degree	Percentage (%)
Science	17.6
Electronic/Electrical Engineering	70.6
Mechanical Engineering	11.8

Table 1: Summary of applicant backgrounds

Learning strategies

To a lesser extent, the prefered learning technique of applicants was surveyed. As reported in the previous section, applicants had on average 5 years industry experience and 57% of the applicants were currently employed. This creates an issue for learning delivery strategies for those people who are working full-time and attempting to study part-time. Anecdotal evidence indicates that many applicants withdraw from the program due to work commitments. This issue is further complicated as 71% of applicants prefer face-face lectures. Alternative methods to face-to-face lectures are CD and Internet based learning. 52% of applicants had experience using internet and CD based learning and did not find these methods better than face-to-face lectures. Applicants indicated that Internet and CD based learning was useful for reference only and not as a method for learning. Other education institutions are adopting internet learning as standard tools (Harsanyi et al., 2002). Figure 4 is a plot of the normalised responses of applicants for preferred methods of learning, with 1 being the highest. Hands-on and face-to-face are the preferred methods.

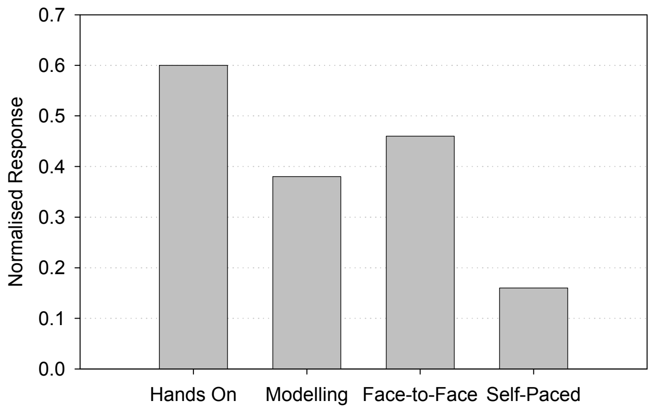

Figure 6: Preferred methods of learning

Conclusions

From the results of the survey conducted, the program structure in place at RMIT has the ability to address the deficiencies of student knowledge and skills. At the same time building on student strengths and through continual program development, new skills and concepts of MEMS technology can be learnt to develop the necessary skills needed for the Australian Microtechnology industry.

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