AC 2008-311: FUTURE OF MICROSYSTEMS TECHNOLOGY EDUCATION, RESEARCH AND OUTREACH AS APPLIED TO 21ST CENTURY MANUFACTURING

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Future of Microsystems Technology Education, Research and Outreach as applied to 21st century manufacturing

Abstract

Micro Electro Mechanical Systems (MEMS) or simply the Microsystems are about tiny electro mechanical devices. These devices are finding their applications in consumer products such as automobiles, communication devices and medical devices. Microsystems are finding rapid growth in their applications and usage. This prompts the need for trained human power to sustain the growth of this nascent technology. This paper explores the opportunities and ways to incorporate Microsystems curriculum in the Engineering Technology programs.

Introduction

Micro Electro Mechanical Systems (MEMS) or Micro Systems Technologies were developed in parallel with the semiconductor industry, but are now experiencing global growth on their own. Microsystems are miniature devices with components smaller than a human hair that can sense, think, communicate and perform complex tasks. Common micro devices include crash sensors used in air bag deployment, ink jet print heads, and biosensors based on nanoprobes. On the sophisticated front, Digital Light Processing (DLP) projection systems are getting popular. At the heart of every DLP projection system is an optical semiconductor known as the DLP chip, which was invented by Dr. Larry Hoenbeck of Texas Instruments in 1987. The DLP chip is probably the world’s most sophisticated light switch. It contains a rectangular array of up to 2 million hinge-mounted microscopic mirrors; each of these micro mirrors measures less than one-fifth the width of a human hair. When a DLP chip is coordinated with a digital video or graphic signal, a light source, and a projection lens, its mirrors can reflect a digital image onto a screen or other surface. The DLP chip and the sophisticated electronics that surround it make up the DLP technology. It is being used extensively in projectors, TVs and movie theatres.

The continued growth in Microsystems or MEMS devices has prompted many Universities to develop graduate-level MEMS research programs as well as some introductory undergraduate courses. However, there is a profound need for standardized materials and technological support and training for academia and industry. A steady stream of highly skilled engineers and technologists produced in this field is very important for the leadership in this nascent technology.

One of the major problems with the adoption of MEMS related courses at the undergraduate curriculum is the need to cover a broad spectrum of introductory information that is essential in understanding the principles. Also there is the need to have sufficient access to design, simulation and manufacturing of these MEMS devices to stimulate the interest in the students. If the students get excited at an early stage, then there is a good probability that they would pursue a career in MEMS related programs which will be the need of the century.

MEMS Vs NEMS

MEMS is expected to make a revolution in optical communication field and moving towards a new technology called NEMS, by changing micro to nano [1].

Nanotechnology will soon become a household word. It is a cutting-edge technology that will revolutionize many sectors of manufacturing over the long-term. Both investment in nanotechnology research and the market for nanotech products are expanding rapidly. Globally, governments in developed nations are pouring about $4 billion annually into research and development of nanotechnology projects. The U.S. government alone invests about $1.4 billion p.a., an increase of more than 10-fold since 1997. The National Science Foundation in America estimates the global market for products containing nanotechnology to be $1 trillion yearly by 2015.

The Japanese government is investing about $1 billion yearly in nanotech research. The European Nanotechnology Trade Alliance (ENTA) estimates government funding of nanotech research in the European region at 480 million Euros for 2004. The same organization counts more than 529 nanotechnology companies in Europe.

Nanotechnology is generally defined as the science of designing, building or utilizing unique structures that are smaller than 100 nanometers in size (a nanometer is one billionth of a meter). This involves microscopic structures that are no larger than the width of some cell membranes. In particular, nanotech may involve the manipulation of materials on the atomic level so that they take on new characteristics, such as increased strength.

Both MEMS and nanotech are today's leaders in the long-term trend of greater and greater miniaturization of electronics and other systems. Analysts at Lyon, France-based Yole Development (www.yole.fr) estimate the global market for MEMS devices at $5.26 billion in 2006, growing to $9.86 billion by 2010.

Nanotechnology has applications in fields such as semiconductors, biotechnology, solar power, chemistry, automotive systems, apparel, coatings, robotics and aerospace. The result will be new ways to solve problems and create products, based on the use of micro components.

Over the next few years, the fastest-growing commercialized uses of nanotechnology will most likely be in coatings, including advanced paints used in demanding environments; specialty chemicals; and textiles. As the technology matures, many more uses will be commercialized.

The Project on Emerging Nanotechnologies (www.nanotechproject.org) listed 475 items in its May 2007 inventory of consumer products that have a nanotech component. This list is twice as large as the 230 products listed in their April 2006 inventory. The new list included 281 health and fitness items (such as cosmetics, sunscreens and sporting goods), 61 food and beverage products, 58 home and garden items and 42 electronics and computer products.

Fortunately, MEMS technology is presently available and widely utilized. A contemporary use of MEMS technology affecting consumers is the micro switch used in passenger-side airbags.

These MEMS switches must be accurate enough to determine when, and at what level of strength, a collision occurs, and then set off the inflation of the air bag quickly enough to protect passengers before the collision's impact reaches them.

Dr. W. David Williams director of Sandia's Microsystems Center, says "I honestly believe that [MEMS] are the new way to keep the country safe".

Williams isn't alone. "The government has its hands on almost every area of [MEMS] research, from cars to optics," says Eric Pearson, director of the Applied Physical Sciences Laboratory at SRI International, a Silicon Valley group that has worked closely with the military for more than 30 years. "They're watching this area very closely."

The government is spending nearly $200 million per year on MEMS research through two agencies: Sandia and DARPA, the Defense Advanced Research Projects Agency, which is responsible for funding cutting-edge military technology. Unlike DARPA, which is only a funding operation, Sandia is a research lab, a maker of MEMS.

Remote sensing is a particularly hot research area. A tiny MEMS sensor, small enough to fit in the buttonhole of a soldier's uniform, could successfully identify the six chemical agents deemed most dangerous by the Pentagon. Another widely desirable defense application: "guided munitions," grenades or mortars equipped with cheap, expendable MEMS that track their movements.

The big defense contractors—Raytheon, Boeing, Lockheed Martin—also are investigating MEMS technology for numerous applications.

It is interesting to analyze and define the core competencies and curriculum requirements for this exciting technology in the applied engineering technology programs.

Core technologies in MEMS

Design of MEMS

MEMS are designed by the creation of individual 2D layers and stacking them to create 3-D structures of varied complexity. There are several commercial software available that provide designers with libraries to make use of proven designs.

Over the last decade, silicon pressure sensors have undergone a significant growth. In most cases, these MEMS devices are manufactured from rectangular or circular diaphragms whose thickness is constant and in the order of some microns[2]. The development of high-performance diaphragm structure is of critical importance in the successful realization of the devices. In particular, diaphragms capable of linear deflection are needed in many pressure sensors. In order to increase the sensitivity, the diaphragm thickness should be thin to maximize the load deflection responses. On the other hand, thin diaphragm under high pressure may result in large deflection and nonlinear effects that are not desirable. It is therefore important to characterize the relationship between diaphragm thickness, deflection, and sensitivity, both analytically and experimentally in order to establish the design guidelines for micro pressure sensors.

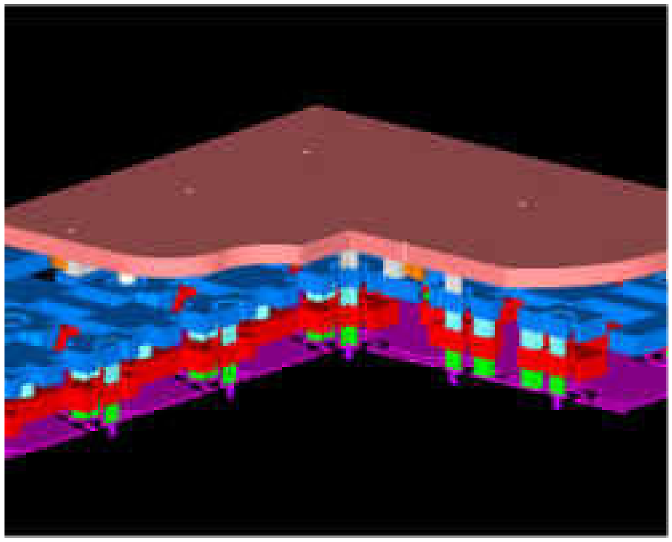

Figure 1. MEMS Design Tool

These MEMS design tools will provide designers with visualizations for making changes and approve the correct designs for building these devices (Figure 1).

Simulation

The simulation packages enable designers to virtually build their products and approve of the manufacturing process (Figure 2).

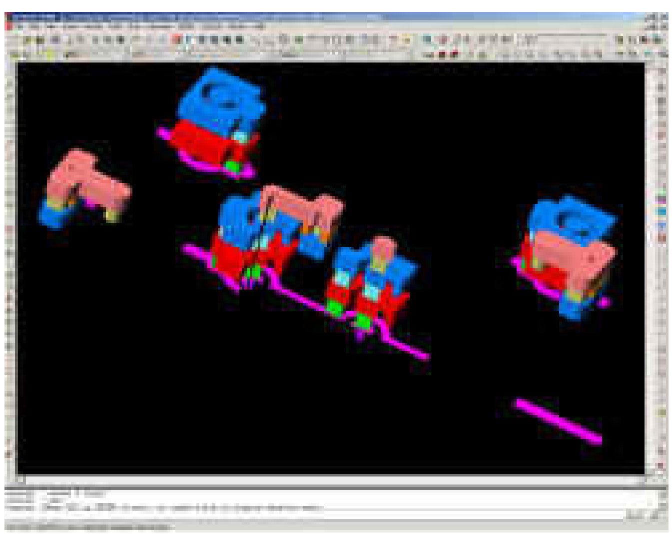

Figure 2. MEMS Simulation

MEMS Fabrication

MEMS fabrication technology is diversifying and achieving a very high level of sophistication. The MEMS fabrication technology is not primarily about size or making use of silicon for building high-performance mechanical applications devices. But, on the contrary to popular notion this technology is about the emergence of new manufacturing technology that will for the manufacture of complex elctromechanical systems using batch fabrication techniques and packaging these elements with electronics[3].

MEMS Testing

Since the early days of the IC industry, wafer-level test has been possible using precision-controlled wafer probers to step from die to die on the wafer, making electrical contact using needle probes. Over time, the requirements to accomplish this testing have become more severe, requiring more sophisticated probers and probe cards. While challenging, these requirements have been met using available technology.

Although it requires a new generation of test equipment, testing MEMS devices is challenging but not impossible.

Testing MEMS devices at wafer level can be accomplished and may save substantial money by not sending bad die through expensive packaging and packaging test. The testing of these devices requires MEMS-specific test strategies, equipment, and designs. Bringing in test partners and vendors at the earliest possible date will save both time and money.

Advanced MEMS testing

Advanced testing methods for the dynamics of micro devices are necessary to develop reliable, marketable micro electro mechanical systems. The main purpose for MEMS testing is to provide feedback to the design-and-simulation process in an engineering development effort. This feedback should include device behavior, system parameters, and material properties. An essential part of a more effective micro device development is high-speed visualization of the dynamics of MEMS structures (www.bsac.edu).

DARPA is into the development of advanced technologies that enable up to 10 Gigabit-per-second streams between end systems over a shared, wide-area infrastructure. This project will extend the capabilities of the optical-characterization facilities at the remote location for dynamic and static behavior of MEMS to users across the country through their use of the new Gbit/s SuperNet in a Virtual-Laboratory environment with SuperNet connection to advanced MEMS CAD and Simulation tools (Figure 3).

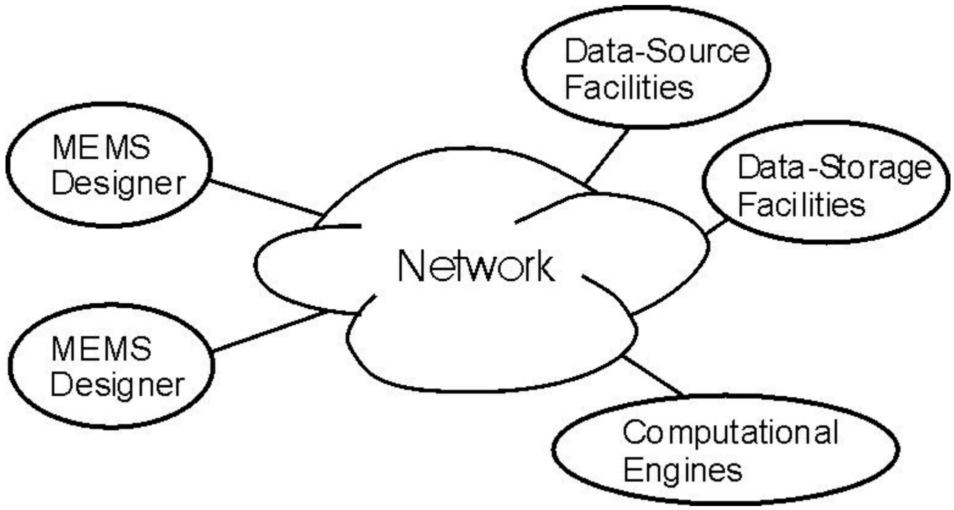

Figure 3: Logic Arrangement of MEMS Facilities connected through the SuperNet.(www.bsac.edu)

Current MEMS curriculum

The present state of Microsystems technology is comparable to the integrated circuit technology about three decade ago[4]. It is clearly going to be a dominant technology sought after by the universities and industries. Both commercial volume and patents on MEMS are growing at rates exceeding 20% annually. The educational components of MEMS technology, now in its early stages, must keep with the environment. Most universities with engineering technology programs will have to teach MEMS technology soon. The subsequent sections are presented with the approach that engineering technology programs can consider to get a head-start with this emerging technology. Three courses on the production and applications of MEMS, which are tentatively planned for the University of Texas at Brownsville and University of Northern Iowa in the coming academic year, are outlined. Approaches in handling laboratory courses on MEMS are also presented.

MEMS courses for Engineering Technology programs

The proposed three course sequence of MEMS technology in the Engineering Technology program addresses the competency requirements of technicians and technologist emerge from this program.

The courses are designed to stimulate and sustain interest in the MEMS technology with the students and they learn to design and fabricate micro devices, and learn where they are used and how they work.

A High School graduate student can get a job as Equipment Operator or Technologists intern after completing two courses – Introduction to MEMS technology and MEMS fabricating methods. When these courses and the Advanced MEMS are coupled with regular

Manufacturing/Mechanical/Electronics Technology core courses and the required Math, Science and Communications will qualify students, employments as Technologists in MEMS industries.

The Table 1 given below depicts the competency levels of technologists required to find the levels of technician's grade in the MEMS industries.

Table 1 Competency of Technologists.

Qualification	Add	Competency	Designation
High School Graduate	+	Introduction to MEMS MEMS Fabrication Methods	Equipment Operator
AAS Degree	+	Three MEMS courses	Technologist
Technologist	+	Diligence & Excellence	Sr. Technologist
Sr. Technologist	+	Technical Mastery	Lead Technologist
Sr. Technologist	+	Organization & People Skills	Production Supervisor

The Table 2 shown below depicts the relationship between competencies and designations of an MEMS Engineer from an undergraduate Engineering technology program.

Table 2 Competency of Engineering Technologists.

Qualification	Add	Competency	Designation
Engineering Technology B.S. Degree Programs	+	Introduction to MEMS MEMS Fabrication Methods Advanced MEMS	Engineer
Graduate Engineering Technology programs	+	Research	Research Engineer
Engineering Technology B.S. Degree Programs	+	MBA Program	Engineering Management

Infrastructure for course offerings:

One of the profound bottle necks in the offer of skill development MEMS courses is the infrastructure, in particular the clean room. Establishment of a typical clean room with associated fabrication and testing facility costs upwards of a million dollars with the continuous maintenance expense which is also very high. As such it is very difficult to establish one in each of the university. Already there are a number of universities that have established facilities which are not being highly utilized. Hence a win-win situation is to have a group of colleges that can be associated with a regional clean room (which is already existing or establishing a new one) so that the resources could be optimally utilized. Further, most of the universities have been utilizing 3D CAD such as Solidworks and Inventor, and FEA techniques in their curriculum. It would be possible to use these for the purpose of designing and simulating MEMS devices. Also the actual MEMS specific design software should be available at low cost for the academic use. In this effort probably NSF and Sandia National Laboratories can take a lead role in establishing such regional clusters.

MEMS Curriculum

The proposed curriculum in MEMS in the Engineering/Industrial Technology Departments at the participating Universities is structured to infuse the above discussed competencies in three course sequence. The proposed curriculum starts from certificate study and finishes at the undergraduate level. Three new undergraduate level MEMS courses are proposed: "Introduction to MEMS" for entry –level students, MEMS fabrication methods for juniors and the Advanced MEMS for senior undergraduate students. These courses are designed with a mix of theory and experiments. MEMS actually builds upon the technologies that are already part of the curriculum. Hence it is possible that the students with these three courses, together with the capstone design project (if that can be oriented to MEMS for this set of students) can achieve reasonable proficiency in microsystems. Should the student like to further specialize can proceed for graduate programs which are already established in a number of universities. It is observed from a survey that the students are interested in taking courses in emerging technologies such as MEMS.

Introduction to Micro-electromechanical Systems (MEMS)

This is the first course on the principles and engineering of micro-electromechanical systems - an introduction to materials and basic devices with examples of applications for sensing and actuation. Lectures will be complemented with a set of laboratory experiments and a project where students design a simple MEMS device in the process.

Course objectives:

This is a survey course covering the exciting interdisciplinary field of MEMS. The nature of engineering at the micro scale, manufacturing and design techniques, micro device applications, issues concerning MEMS commercialization, and future trends are thoroughly discussed. Applications and relevance to MEMS: sensor devices, biomedical devices, and telecommunication devices are explored. The field of Microsystems technology is highly interdisciplinary, drawing from all major technical fields, including physics, chemistry, biology, and materials science. No one course can probe this field in great depth. However, it is hoped that, upon completion of this course, the student will be motivated enough about Microsystems technology to confidently enter or follow the field.

Course outcomes:

After completion of this course, students should be able to

- describe current and emerging manufacturing techniques for MEMS;

- describe examples of MEMS devices in industries such as automotive, aerospace, biotechnology telecommunications, and fiber-optic communications;
- describe the electronic, physical and chemical principles involved in the successful operation of a wide variety of MEMS devices;
- intelligently discuss issues relating to the design and implementation of MEMS devices, including the strengths and weaknesses of MEMS applications;
- discuss market forces that drive the development of MEMS devices and technology.

MEMS fabrication methods

Course objectives:

The objectives of this course are to go beyond the design stage in Micro-Electro-Mechanical Systems (MEMS) to provide students with a strong background in fabrication, testing and characterization of MEMS. The main focus is to understand the fundamental challenges and limitations involved in developing and testing MEMS devices and systems. Various MEMS fabrication process will be discussed. Simulation and laboratory experiments are key components of this course.

Course Outcomes:

Students should leave the course with the ability to

- demonstrate a basic understanding of silicon electronic device and MEMS device fabrication processes;
- demonstrate good laboratory procedures and laboratory notebook maintenance;
- demonstrate hands on experience and working knowledge of microelectronics or MEMS processing steps and process modules;
- demonstrate hands on experience and working knowledge of electronic or MEMS device testing and characterization.

Advanced MEMS

Course objectives:

The objectives of this Course are to investigate the entire process of developing MEMS devices. Along the way, topics of discussion will include picking an appropriate application of the MEMS technology, designing a MEMS device, MEMS fabrication and packaging techniques, the challenging aspects of characterizing MEMS devices, and the unique physical environment that exists at the micron scale. Other discussions will address the existing MEMS market, the future of MEMS and the difficulties associated with establishing a successful MEMS business. The course will be taught through real world examples of existing MEMS implementations, drawing on both the successes and failures of past efforts to paint a realistic view of this exciting yet challenging new technology.

Course outcomes:

Students will be able to

- understand the definition of a "good" MEMS application
- understand MEMS fabrication constraints and typical process flows
- understand commonly used MEMS design concepts and issues
- understand how to discriminate between "good" and "bad" designs
- appreciate the significance of package design on MEMS performance
- understand the challenges associated with "pulling it all together"
- understand the current and future markets

There are several text books available in the area of MEMS that cover the science and technical aspects of these devices. However, there is a need for new and effective text books in MEMS that will address the engineering technology program objectives.

Conclusion:

A minor in MEMS including three course sequence for Engineering Technology students is presented in the paper. It is hoped that specializing in this technology of micro world will be of immense advantage to technology students in securing exciting jobs in all levels of MEMS manufacturing industries. Developing new programs and curriculum will provide the microsystems industry with a flexible set of educational resources and a core of trained human power while increasing the general public's awareness. This will also facilitate in the future creation of standardized curriculum, educational programs and industry validated certification.

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