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Online Resources in MEMS Technology for Professional and Educational Development

Matthias W. Pleil, Ph.D.[1], G.H. Massiha, Ph.D.[2]
[1] University of New Mexico, Schools of Applied Technologies, Albuquerque
[2] University of Louisiana at Lafayette, Department of Industrial Technology, Lafayette

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ABSTRACT

Over the last twenty years, the National Science Foundation (NSF) through its Advanced Technological Education (ATE) program has funded many ATE centers across the United State of America to advance the technician level work force in the Country. One of these centers is the Southwest Center for Microsystems Education (SCME) located at the University of New Mexico. The SCME offers educational materials and professional development at no cost. These materials and professional development opportunities include sponsored conferences, downloadable written materials for instructors and students, YouTube channels providing lectures, animations and videos, hands-on kits for the classroom, micro and nano films, webinars, online distance learning courses and mentoring opportunities for educators.

Corresponding Author:

G.H. Massiha,
Department of Industrial Technology,
University of Louisiana at Lafayette,
Lafayette, LA 70504.
Email: massiha@louisiana.edu

1. INTRODUCTION

In order to continually evolve and innovative STEM and Tech programs, conventional technical high schools, colleges, and universities, have the responsibility to seek out and implement new, innovative, emerging and technically engaging educational materials for their students. Given today's economy, these educational organizations may not have the resources (financial as well as trained educators), to teach technically advanced topics. The overall MEMS industry has grown at a 9% overall compound annual growth rate (CAGR) over the last 10 years and is projected to grow at 12-13% CAGR through 2018 [1]. Certain MEMS sectors are growing at much higher rates, such as BioMEMS (30%), SAW Devices (27%), MEMS applications in smart phones and tablets are growing at 34% expecting to reach $2.4B in revenue in 2014. The motion sensors segment (gyros, accelerometers, compass, pressure sensors), related to consumer applications, is growing at the much higher rate of 46% [2]. It is also established that the United States produces approximately half of all microsystems and has the most MEMS foundries of any country. In addition, there are many small startup companies poised to rapidly grow which will be in need of technicians as they move from prototype to high volume production.

2. SOUTHWEST CENTER FOR MICROSYSTEMS EDUCATION MISSION

The Southwest Center for Microsystems Education (SCME) is a NSF funded ATE Center of Excellence that identifies microsystems technician competencies, creates and disseminates educational materials and models, and provides professional development activities to develop a skilled microsystems workforce ready for research and development and industry manufacturing environments. By supporting the growth and enrichment of technician education programs, the SCME will improve the competitive position of established and emerging economic clusters and thereby improving the United States capability to support the micro/nano industry and related sector. Figure 1 a graphic depiction of how SCME provides value to its stake holders.

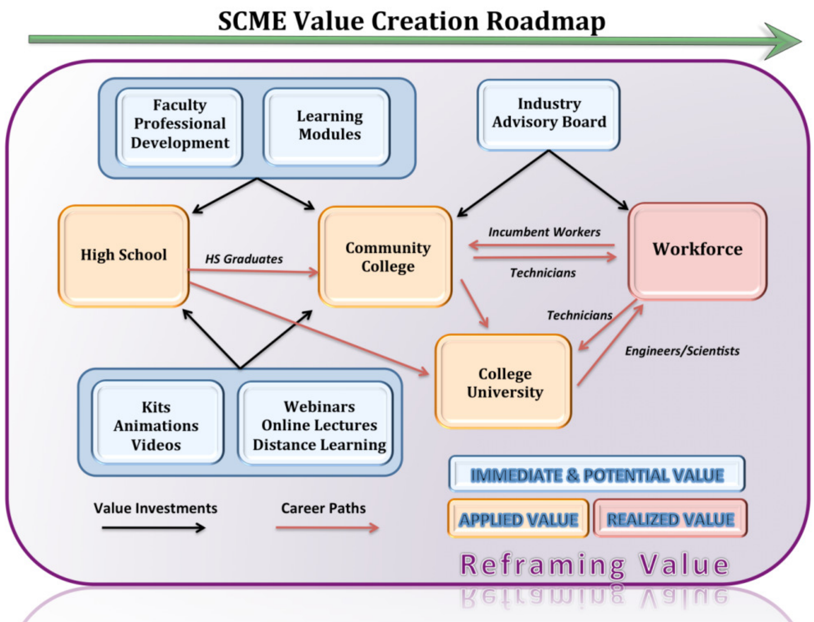

Figure 1. SCME Value Creation Roadmap

3. WHAT ARE MEMS?

MEMS stands for Micro-electro-mechanical-systems. MEMS are also referred to as Microsystems, which include MOEMS (Micro-optical), Microfluidics, BioMEMs, and semiconductors. MEMS include very small devices or groups of devices that include the integration of both mechanical and electrical components. The sizes of these systems are from a few microns millimeters. Structures within these systems can be sub-micron, and coatings which functionalize BioMEMS and biochemical sensors, for example can be nanometers thick or even sub-nano for molecular monolayers. MEMS are usually constructed on a single chip that contains one or more micro-components and the input/outputs for electrical signals, fluidic micro channels, optical fibers and openings to the environment. The components may include different types of sensors, transducers, actuators, electronics, chemically and biologically functionalized parts, and structures (cantilevers, valves, channels, chambers, gears, sliding mirrors, and thin film diaphragms are examples). Each component type is designed to interface with an input such as light, gas molecules, fluid, specific types of radiation, pressure, temperature, or biomolecules. MEMS are devices that can sense, think, act and communicate and more recently, harvest energy. Through the miniaturization of these macro-sized devices, improved fabrication quality controls, and the ability to fabricate large numbers of devices, the costs of manufacturing per part continues to decline resulting in the double digit market growth rates seen in bio-medical and consumer product applications.

MEMS are wide-ranging in their applications and construction. There can be one microdevice or element on a single chip or many devices containing dozens of components or elements on a single chip. The interaction of these components working together makes up a microelectromechanical system or MEMS. MEMS elements work independently as a solitary device or work together in large arrays or combinations in order to perform complicated tasks. As an example, Figure 2 and 3, depict different views of the Texas Instruments Digital Light Processor (DLP) Chip. The DLP has been one of the most commercially successful MEMS based systems to date. The DLP chip is made up of over 1 million electrostatically driven individual MEMS mirrors, nine of which are shown in Figure 3. The MEMS component is referred to as the Digital Mirror Device or DMD. This mems-based system was developed by Larry Hornbeck of Texas instruments starting in the 1980’s resulting in the first commercially viable product starting in 1995 with a

VGA (640x480) resolution projection system [3]. Current systems for cinema and large venues contain three chips (one for each color) of over 8M mirrors [4].

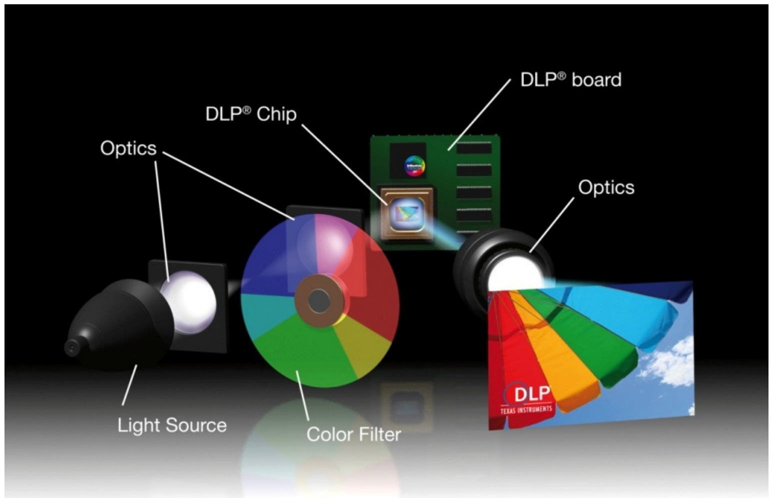

Figure 1. Texas Instruments Digital Light Processing system shown here as part of a high-definition projection system. Image used with permission, courtesy of Texas Instruments.

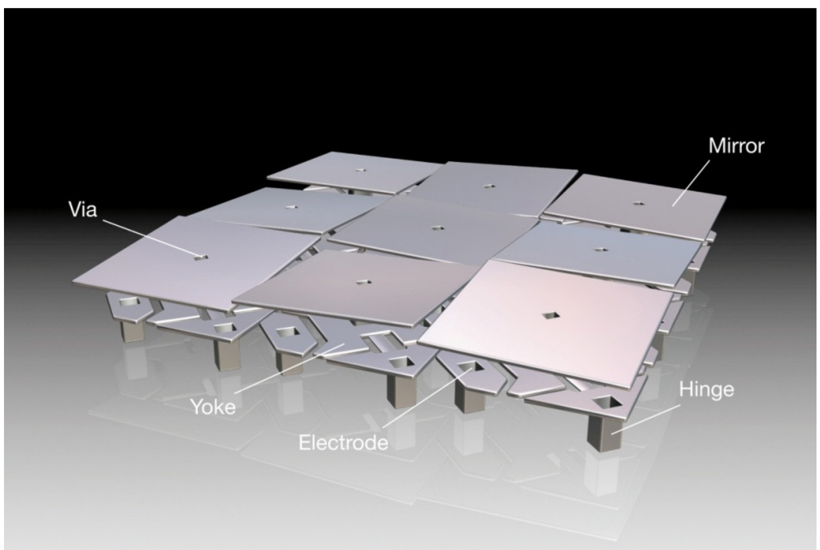

Figure 3. A small portion of the Digital Mirror Device showing nine of the million mirror components found in this Texas Instruments MOEMS. Each mirror is approximately 20 micrometers per side. Image courtesy of Texas Instruments

Therapeutic biomedical MEMS is another rapidly growing market segment. These applications include cochlear implants, artificial retinas, sub cutaneous drug delivery, and glucose micro-sensors with microfluidic pumps to dispense insulin. Figure 4. shows how small a micro-fluidic insulin pump can be making the possibility for sub-cuteness drug delivery systems a reality. Bio-chemical MEMS used in diagnostics systems include lab on a chip devices which are used to detect genetic variation, test drugs and grow cells on micro array platforms, detect harmful bio-chemical gasses in homeland security applications, food contamination utilizing micro-cantilever-based arrays, or surface-acoustic wave (SAW) based devices.

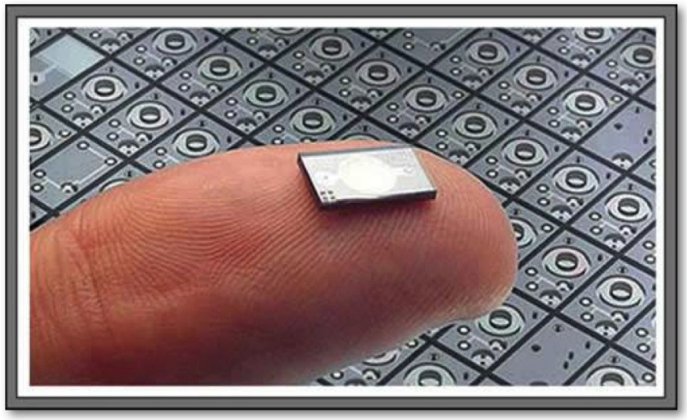

Figure 4. An example of an insulin micro fluidic pump. Image courtesy of Debiotech SA.

4. HOW MICROSYSTEM CAN ENHANGE 2 YEAR TECH PROGRAMS

MEMS are found in a wide range of biotechnology, transportation, homeland security, and consumer product applications, as such, they can be used to engage STEM students at the secondary and post-secondary levels. Common microsystems applications that can be leveraged to keep the interest of students include air bag crash sensor systems, inkjet print heads, DLP projection systems, motion sensors found in cell phones, tablets, and game controllers, as well as pressure sensors, accelerometers, and micro-gyros found in automotive and aerospace applications. MEMS typically contain an integrated set of otherwise disparate technologies (e.g., mechanics, fluidics, materials, energy, photonics, biology, etc.) that span the entire spectrum of STEM components. Moreover, MEMS is one of the last bastions of hands-on learning, as colleges and universities move to replace physical labs with computer stations and simulators. The challenge is to engage and develop an agile, well-educated workforce to support this growth and range of needed skills. The Southwest Center for Microsystems Education is the only ATE center to focus on microsystems and can be a source for educational materials to enhance the STEM curriculum and modernize curriculum found in electronics, bio-tech, photonics and engineering technology programs.

Through a faculty development strategy that includes one-day, two-day, and week-long workshops, as well as online webinars and short courses, SCME staff have invested time and resources into training faculty who adapt and integrate MEMS education and training into the classes that they teach. To date, more than 400 educators from 30 states have participated in MEMS workshops and short courses hosted by the SCME at the University of New Mexico, and its partner institutions: Central New Mexico Community College (CNM), Southwestern Indian Polytechnic Institute (SIPI), North Dakota State College of Science (NDSCS), University of South Florida (USF) and most recently, the University of Michigan’s Lurie Nanofabrication Center. Educators report having impacted thousands of students and delivered over 70,000 student-hours of instruction student impact. The center will continue to host workshops for approximately 80 faculty per year and provide classroom resources for these faculty to teach microsystems design and fabrication. SCME continues to reach out to community colleges nationwide that have an expressed interest in microsystems. SCME also works with secondary schools, as part of its MEMS awareness mission, by engaging secondary educators as MEMS cleanroom trainees, educational materials developers, and classroom adopters. SCME supports dual-credit/dual enrollment Introduction to MEMS course that brings in area high school student and teachers. SCME holds periodic industry advisory meetings to ensure that they support the development of microsystems educated technicians to support this rapidly growing industry. SCME has developed a large number of educational learning modules based on the needs expressed by the microsystems industry advisory board and surveys. Many of the modules were built around the STEM concepts necessary to fabricate a simple MEMS device, the pressure sensor. These include topics on cleanroom safety (MSDS, NFPA, PPE) and protocol, crystallography and anisotropic etching, photolithography, thin film deposition, silicon oxide growth, metal evaporation. Hands-on kits to bring the cleanroom into the classroom have been developed and are available for sale (cost-recovery) and to partners. All written materials are available for download from the SCME-NM.org website and there are many supplemental videos, and animations on the SCME YouTube Channel. Figures 5 and 6 show the front and backside of student fabricated MEMS pressure sensors. This is the end product of a series of processes which include silicon nitride deposition, photolithography patterning (resist coat, expose and develop), deep reactive ion etching, metal evaporation, lift-off and anisotropic wet etching of silicon crystal. These chips are fabricated by students, and workshop attendees, at the University of New Mexico's Manufacturing Training and Technology Center (MTTC). This process has been transferred to the USF, NDSCS and most recently, University of Michigan.

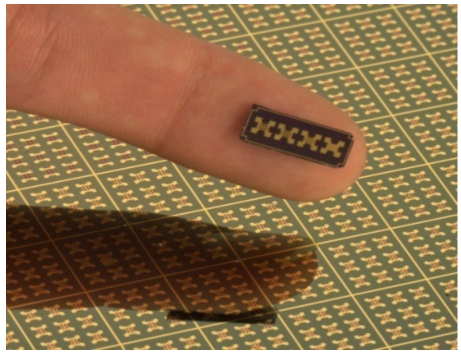

Figure 5. A simple MEMS pressure sensor chip containing four individual sensors. The front side shown here contains the Wheatstone bridge circuit on top of the silicon nitride membrane.

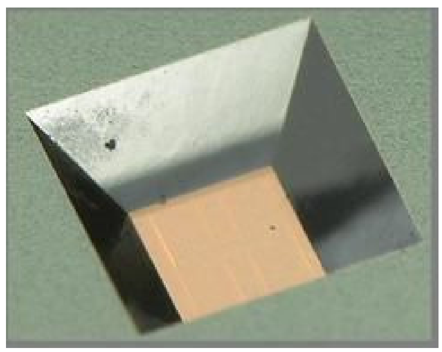

Figure 6. The backside of an individual pressure sensor shows the anisotropically etched crystalline silicon chamber. Students learn to apply crystallography concepts to the fabrication of a MEMS device.

In order to bring the concepts of how a pressure sensor is made and how it works, SCME has developed a "Pressure Sensor Macro Model Kit." Figure 7 shows the working system in a classroom environment. The Wheatstone bridge circuit theory is a component of the kit, represented in Figure 8.

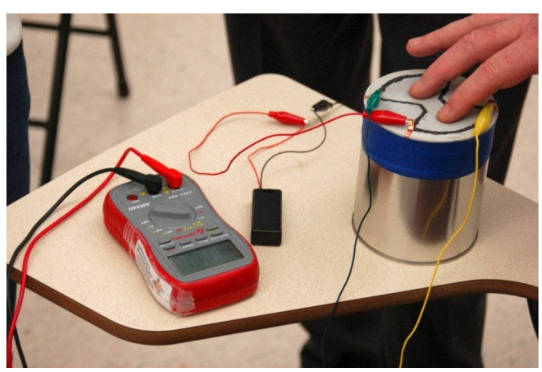

Figure 7. A functioning macro version of the micro-pressure sensor.

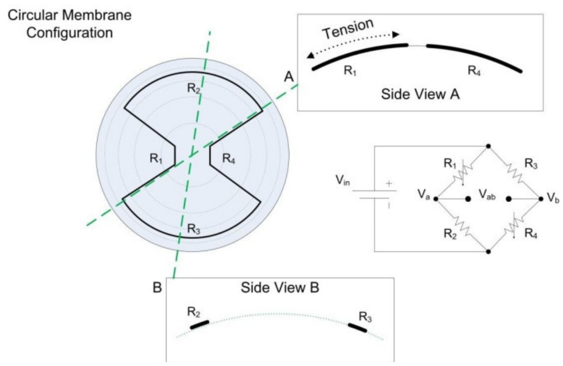

Figure 8. Schematic of the pressure sensor showing how the piezo resistive elements react to stress and the corresponding Wheatstone bridge diagram.

Since BioMEMS market segment is one of the fastest growing areas in the MEMS field, SCME collaborated with Bio-tech partners associated with the Bio-Link ATE center to create a series of BioMEMS educational modules and kits. Figure shows educators learning about one of the more interesting application of BioMEMS, the DNA Micro-array.

Figure 9. College educators learning about DNA Microarray MEMS at the annual MNT Conference.

5. HOW SCME CAN ASSIST FACULTY AND STUDENTS

SCME offers many avenues for the educator to bring MEMS into their STEM classroom. All of the 40+ Learning Modules can be downloaded from the SCME website. Each module is built out of several shareable content objects (SCO's) which include primary knowledge (reading), activity (homework, hands-on labs, worksheets), and assessment SCO's. Every learning module comes in pairs, the "Participant" and "Instructor" guides, the later having the answers to the assessment and activity questions, learning maps and notes to assist in the understanding and facilitating of student learning. There are also PowerPoint files for each module, which the instructor may use and modify and adapt, for his or her application. Supplemental materials are also available including a series of lectures, animations and videos on the SCME and PI YouTube channels.

SCME is in the process of building an online, distance learning series of short courses to enhance its ability to spread these unique educational materials to a larger audience. These can be configured to meet the needs of individual instructors and institutions. This is being done on an open source learning management system (MOODLE) housed on the SCME website.

One of the best resources are the dozen hands-on kits that can be obtained through the SCME Kit-store. These include Micro and Nano films with supplemental written materials, Anistropic Etch of Crystalline Silicon, Lift-off process, Dynamic Cantilever, Pressure Sensor Process and Macro Model kits, DNA Microarray, Crystallography, “Rainbow Wafer” (science of thin films), and others. SCME is available to assist the educator in bringing these to the classroom.

6. SUMMARY

Southwest Center for Microsystems Education (SCME) web site, http://scme-nm.org/, has all of the written materials available for free download. Teachers are recommended to register to gain access additional materials such as instructor resources as mentioned above. The kit store allows one to order kits online for reasonable cost, all proceeds are used to replenish the kit stock. Webinars are also given and there is a series of over a dozen archived available. Workshops are given at the UNM site as well as the partner institutions and these are generally free. The annual Micro Nano Tech Conference is co-sponsored and hosted by SCME and the Nano ATE Centers (NACK, Nano-Link, SHINE, NEATEC) as well as MATEC. All of these centers also have a vast set of educational materials available and most of it is free.

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Online Resource Links

SCME: http://scme-nm.org/

- Catalog: http://scme-nm.org/index.php?option=com_docman&task=cat_view&gid=97&Itemid=226
- Educational Materials (downloadable, create an account to access Instructor Materials): http://scme-nm.org/index.php?option=com_docman&task=cat_view&gid=97&Itemid=53
- Kit Store: https://secure.touchnet.com/C21597_ustores/web/store_cat.jsp?STOREID=44&CATID=67&SINGLESTORE=true
- YouTube Channel:
  https://www.youtube.com/user/SCME2012
  https://www.youtube.com/channel/UCyAvnKdlKo3WKkQOragW2EA

Partner ATE Centers

- **NACK - http://nano4me.org/**
- **NEATEC - http://neatec.org/**
- **Nano-Link - http://www.nano-link.org/**
- **MATEC - http://matec.org/**

BIBLIOGRAPHY OF AUTHORS

Matthias Pleil, Ph.D. is a Research Professor of Mechanical Engineering at University of New Mexico and Faculty and a faculty member at Central New Mexico Community College. He is the Principal Investigator for the Southwest Center for Microsystems Education; a National Science Foundation supported Advanced Technological Education Center at the University of New Mexico. He has over 12 years of experience in Semiconductor Manufacturing from both Texas Instruments and Philips Semiconductors, where he worked as a Senior Process and Equipment Engineer and Engineering Manager in Photolithography, Yield and Metrology.

G. H. Massiha, Ph.D., is a Louisiana Board of Region Professor of Engineering. His areas of research interest are robotics, alternative energy, and automation manufacturing. Dr. Massiha has twenty years of full-time faculty teaching and twenty five years of research experience. His areas of expertise are in experimental and theoretical microelectronics, condensed matter physics, and solar energy research, with emphasis on the engineering reliability and characterization of integrated circuits. In addition, he works on a variety of control and robotics and energy management projects.