An Overview Of Micro Electro Mechanical Systems And Challenges Of Mems

[1] S.Madhava Reddy, [2] J Pavan kumar, [3] K.Sudhakar Reddy

[1, 3] Professor, [2] Assistant Professor
[1, 2,3] Dept. Of Mechanical Engineering,
[1, 2, 3] Mahatma Gandhi Institute of Technology,
[1,2,3] Gandipet,Hydderabad -500075,Telangana-India
Email: smrmech@gmail.com

Abstract— Micro-Electro-Mechanical Systems, or MEMS, is a technology that in its most general form can be defined as miniaturized mechanical and electro-mechanical elements that are made using the techniques of micro fabrication. The critical physical dimensions of MEMS devices can vary from well below one micron on the lower end of the dimensional spectrum, all the way to several millimeters. Likewise, the types of MEMS devices can vary from relatively simple structures having no moving elements, to extremely complex electromechanical systems with multiple moving elements under the control of integrated microelectronics. The one main criterion of MEMS is that there are at least some elements having some sort of mechanical functionality whether or not these elements can move. The term used to define MEMS varies in different parts of the world. In the United States they are predominantly called MEMS, while in some other parts of the world they are called “Microsystems Technology” or “micro machined devices”. This report deals with the field of micro-electromechanical systems or MEMS. MEMS encompass the process-based technologies used to fabricate tiny integrated devices and systems that integrate functionalities from different physical domains into one device. Such devices are fabricated using a wide range of technologies having in common the ability to create structures with micro-scale and even nano scale accuracies. The products range in size from a few microns to millimeters. These devices have the ability to sense, control and actuate on the micro scale and generate effects on the macro scale.

Keywords— Micro electromechanical System, miniaturization, actuators, sensors

I. INTRODUCTION

Over the past several decades MEMS researchers and developers have demonstrated an extremely large number of micro sensors for almost every possible sensing modality including temperature, pressure, inertial forces, chemical species, magnetic fields, radiation, etc. Remarkably, many of these micro machined sensors have demonstrated performances exceeding those of their macro scale counterparts. That is, the micro machined version of, for example, a pressure transducer, usually outperforms a pressure sensor made using the most precise macro scale level machining techniques. Not only is the performance of MEMS devices exceptional, but their method of production leverages the same batch fabrication techniques used in the integrated circuit industry – which can translate into low per-device production costs, as well as many other benefits. Consequently, it is possible to not only achieve stellar device performance, but to do so at a relatively low cost level. Not surprisingly, silicon based discrete micro sensors were quickly commercially exploited and the markets for these devices continue to grow at a rapid rate. More recently, the MEMS research and development community has demonstrated a number of micro actuators including: micro valves for control of gas and liquid flows; optical switches and mirrors to redirect or modulate light beams; independently controlled micro mirror arrays for displays, micro resonators for a number of different applications, micro pumps to develop positive fluid pressures, micro flaps to modulate airstreams on airfoils, as well as many others. Surprisingly, even though these micro actuators are extremely small, they frequently can cause effects at the macro scale level; that is, these tiny actuators can perform mechanical feats far larger than their size would imply. For example, researchers have placed small micro actuators on the leading edge of airfoils of an aircraft and have been able to steer the aircraft using only these microminiaturized devices. Components of MEMS are shown in fig 1.

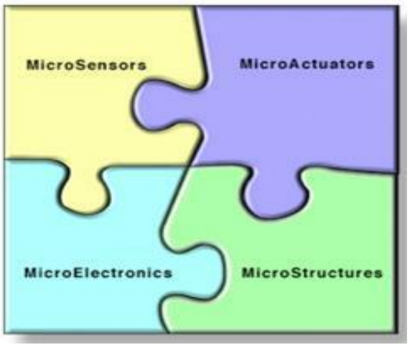

Fig1. Components of MEMS

MEMS devices are very small, their components are usually microscopic. Pumps, valves, gears, pistons, as well as motors and even steam engines have all been fabricated by MEMS. However, two points are worth consideration. MEMS are not just about the miniaturization of mechanical components or making things out of silicon (in fact, the term MEMS is actually misleading as many micro machined devices are not mechanical in a strict sense). MEMS is a manufacturing technology; a paradigm for designing and creating complex integrated devices and systems using batch fabrication techniques similar to the technologies used in IC manufacturing or standard machining technologies extended in to the micro and nanometer area. Secondly, not all miniaturized components are as yet useful or commercialized. Although micro scale gearboxes, pumps and steam engines are fascinating to see, the practical problems associated with the operating (wear, energy efficiency etc), and the high cost of creating them, often stands in the way of successful commercialization. In the most general form, MEMS consist of mechanical microstructures, micro sensors, micro actuators and microelectronics, all integrated onto the same silicon chip. Micro sensors detect changes in the system's environment by measuring mechanical, thermal, magnetic, chemical or electromagnetic information or phenomena. Microelectronics processes this information and signals the micro actuators to react and create some form of changes to the environment this is shown schematically in Figure 2.

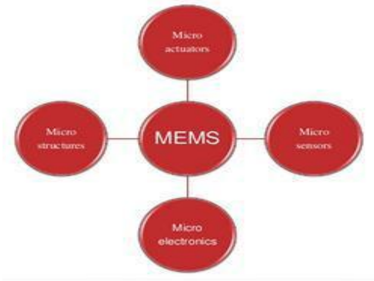

Figure2. Schematic illustration of MEMS components

Micro-optoelectromechanical systems (MOEMS) is also a subset of MST and together with MEMS forms the specialized technology fields using miniaturized combinations of optics, electronics and mechanics. Both their Microsystems incorporate the use of microelectronics batch processing techniques for their design and fabrication. There are considerable overlaps between fields in terms of their integrating technology and their applications and hence it is extremely difficult to categories MEMS devices in terms of sensing domain and/or their subset of MST. Classifications of Microsystems technology is shown in fig 3.

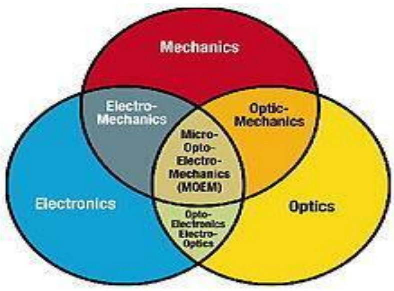

Figure 3. Classifications of Microsystems technology MEMS devices can be classified into two categories, mainly sensors and actuators. Sensors are non-intrusive while actuators modify the environment.

Sensor

A sensor's sensitivity indicates how much the sensor's output changes when the input quantity being measured changes. For instance, if the mercury in a thermometer moves 1 cm when the temperature changes by 1 °C, the sensitivity is 1 cm/°C. Some sensors can also affect what they measure; for instance, a room temperature thermometer inserted into a hot cup of liquid cools the liquid while the liquid heats the thermometer. Sensors are usually designed to have a small effect on what is measured; making the sensor smaller often improves this and may introduce other advantages.[citation needed] Technological progress allows more and more sensors to be manufactured on a microscopic scale as micro sensors using MEMS technology. In most cases, a micro sensor reaches a significantly higher speed and sensitivity compared with macroscopic approaches. MEMS inertial sensors are shown in fig 4.

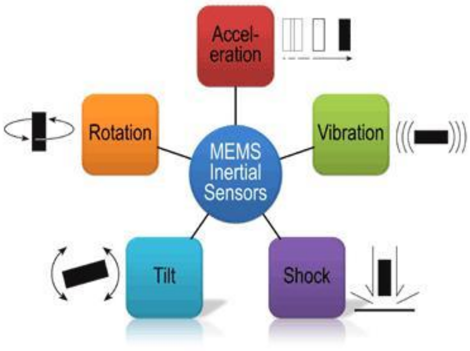

Fig 4. MEMS inertial sensors

Actuators

An actuator is a device that converts an electrical signal into an action. It can create a force to manipulate itself, other mechanical devices, or the surrounding environment to perform some useful function. More recently, the MEMS research and development community has demonstrated a number of micro actuators including: micro valves for control of gas and liquid flows; optical switches and mirrors to redirect or modulate light beams; independently controlled micro mirror arrays for displays, micro resonators for a number of different applications, micro pumps to develop positive fluid pressures, micro flaps to modulate airstreams on airfoils, as well as many others. Surprisingly, even though these micro actuators are extremely small, they frequently can cause effects at the macro scale level; that is, these tiny actuators can perform mechanical feats far larger than their size would imply. For example, researchers have placed small micro actuators on the leading edge of airfoils of an aircraft and have been able to steer the aircraft using only these microminiaturized devices. A surface micro machined electro-statically-actuated micro motor fabricated is shown in fig 5.

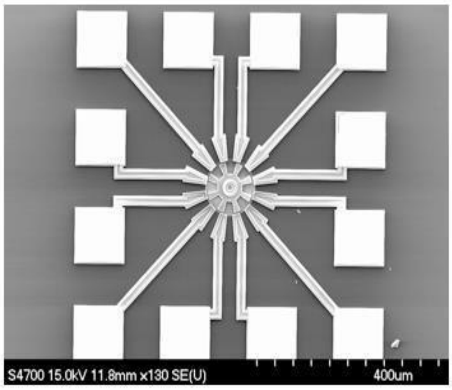

Fig 5. A surface micro machined electro-statically-actuated micro motor fabricated by the MNX. This device is an example of a MEMS-based micro actuator.

II. APPLICATIONS

There are numerous possible applications for MEMS and Nanotechnology. As a breakthrough technology, allowing unparalleled synergy between previously unrelated fields such as biology and microelectronics, many new MEMS and Nanotechnology applications will emerge, expanding beyond that which is currently identified or known. Here are a few applications of current interest:

A. Biotechnology:

MEMS and Nanotechnology is enabling new discoveries in science and engineering such as the Polymerase Chain Reaction (PCR) micro systems for DNA amplification and identification, enzyme linked immunosorbent assay (ELISA), capillary electrophoresis, electro portion, micro machined Scanning Tunneling Microscopes (STMs), biochips for detection of hazardous chemical and biological agents, and micro systems for high-throughput drug screening and selection.

B. Medicine

There are a wide variety of applications for MEMS in medicine. The first and by far the most successful application of MEMS in medicine (at least in terms of number of devices and market size) are MEMS pressure sensors, which have been in use for several decades. The market for these pressure sensors is extremely diverse and highly fragmented, with a few high-volume markets and many lower volume ones.

Some of the applications of MEMS pressure sensors in medicine include:

The largest market for MEMS pressure sensors in the medical sector is the disposable sensor used to monitor blood pressure in IV lines of patients in intensive care. These devices were first introduced in the early 1980's. They replaced other technologies that cost over $500 and which had a substantial recurring cost since they had to be sterilized and recalibrated after each use. MEMS disposable pressure sensors are delivered pre-calibrated in a sterilized package from the factory at a cost of around $10.

MEMS pressure sensors are used to measure intrauterine pressure during birth. The device is housed in a catheter that is placed between the baby's head and the uterine wall. During delivery, the baby's blood pressure is monitored for problems during the mother's contractions.

MEMS pressure sensors are used in hospitals and ambulances as monitors of a patient's vital signs, specifically the patient's blood pressure and respiration.

The MEMS pressure sensors in respiratory monitoring are used in ventilators to monitor the patient's breathing.

MEMS pressure sensors are used for eye surgery to measure and control the vacuum level used to remove fluid from the eye, which is cleaned of debris and replaced back into the eye during surgery

Special hospital beds for burn victims that employ inflatable mattresses use MEMS pressure sensors to regulate the pressure inside a series of individual inflatable chambers in the mattress. Sections of the mattress can be inflated as needed to reduce pain as well as improve patient healing.

Physician's office and hospital blood analyzers employ MEMS pressure sensors as barometric pressure correction for the analysis of concentrations of O2, CO2, calcium, potassium, and glucose in a patient's blood.

MEMS pressure sensors are used in inhalers to monitor the patient's breathing cycle and release the medication at the proper time in the breathing cycle for optimal effect.

MEMS pressure sensors are used in kidney dialysis to monitor the inlet and outlet pressures of blood and the dialysis solution and to regulate the flow rates during the procedure.

MEMS pressure sensors are used in drug infusion pumps of many types to monitor the flow rate and detect for obstructions and blockages that indicate that the drug is not being properly delivered to the patient. The contribution to patient care for all of these applications has been enormous. More recently, MEMS pressure sensors have been developed and are being marketed that have wireless interrogation capability. These sensors can be implanted into a human body and the pressure can be measured using a remotely scanned wand. Another application are MEMS inertial sensors, specifically accelerometers and rate sensors which are being used as activity sensors. Perhaps the foremost application of inertial sensors in medicine is in cardiac pacemakers wherein they are used to help determine the optimum pacing rate for the patient based on their activity level. MEMS devices are also starting to be employed in drug delivery devices, for both ambulatory and implantable applications. MEMS electrodes are also being used in neuro-signal detection and neuro-stimulation applications. A variety of biological and chemical MEMS sensors for invasive and non-invasive uses are beginning to be marketed. Lab-on-a-chip and miniaturized biochemical analytical instruments are being marketed as well.

C. Communications

Highfrequencycircuitsarebenefiting considerably from the advent of RF-MEMS technology. Electrical components such as inductors and tunable capacitors can be improved significantly compared to their integrated counterparts if they are made using MEMS and Nanotechnology. With the integration of such components, the performance of communication circuits will improve, while the total circuit area, power consumption and cost will be reduced. In addition, the mechanical switch, as developed by several research groups, is a key component with huge potential in various RF and microwave circuits. The demonstrated samples of mechanical switches have quality factors much higher than anything previously available. Another successful application of RF-MEMS is in resonators as mechanical filters for communication circuits.

D. Inertial Sensings

MEMS inertial sensors, specifically accelerometers and gyroscopes, are quickly gaining market acceptance. For example, MEMS accelerometers have displaced conventional accelerometers for crash air-bag deployment systems in automobiles. The previous technology approach used several bulky accelerometers made of discrete components mounted in the front of the car with separate electronics near the air-bag and cost more than $50 per device. MEMS technology has made it possible to integrate the accelerometer and electronics onto a single silicon chip at a cost of only a few dollars. These MEMS accelerometers are much smaller, more functional, lighter, more reliable, and are produced for a fraction of the cost of the conventional macro scale accelerometer elements. More recently, MEMS gyroscopes (i.e., rate sensors) have been developed for both automobile and consumer electronics applications. MEMS inertial sensors are now being used in every car sold as well as notable customer electronic handhelds such as Apple iPhones and the Nintendo Wii. Applications of mems shown in fig 6.

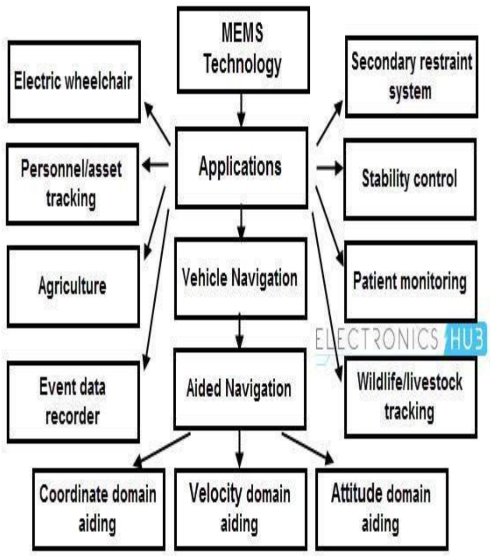

Fig 6. Applications of mems

III. Challenges in MEMS

A. Access to Fabrication

Most organizations who wish to explore the potential of MEMS and Nanotechnology have little or no internal resources for designing, prototyping, or manufacturing devices, as well as little to no expertise among their staff in developing these technologies. Few organizations will build their own fabrication facilities or establish technical development teams because of the prohibitive cost. Therefore, these organizations will benefit greatly from the availability of MNX's fabrication services, which offers its customers affordable access to the best MEMS and nano fabrication technologies available.

B. Packaging

MEMS packaging is more challenging than IC packaging due to the diversity of MEMS devices and the requirement that many of these devices need to be simultaneously in contact with their environment as well as protected from the environment. Frequently, many MEMS and Nano device development efforts must develop a new and specialized package for the device to meet the application requirements. As a result, packaging can often be one of the single most expensive and time consuming tasks in an overall product development program. The MNX staff are experts in packaging solutions for devices for any application

C. Access to Foundries

MEMS companies today have very limited access to MEMS fabrication facilities, or foundries, for prototype and device manufacture. In addition, the majority of the organizations expected to benefit from this technology currently do not have the required capabilities and competencies to support MEMS fabrication. For example, telecommunication companies do not currently maintain micromachining facilities for the fabrication of optical switches. Affordable and receptive access to MEMS fabrication facilities is crucial for the commercialization of MEMS.

D. Design, Simulation and Modeling.

Due to the highly integrated and interdisciplinary nature of MEMS, it is difficult to separate device design from the complexities of fabrication. Consequently, a high level of manufacturing and fabrication knowledge is necessary to design a

MEMS device. Furthermore, considerable time and expense is spent during this development and subsequent prototype stage. In order to increase innovation and creativity, and reduce unnecessary 'time-to-market' costs, an interface should be created to separate design and fabrication. As successful device development also necessitates modeling and simulation, it is important that MEMS designers have access to adequate analytical tools. Currently, MEMS devices use older design tools and are fabricated on a 'trial and error' basis. Therefore, more powerful and advanced simulation and modeling tools are necessary for accurate prediction of MEMS device behavior.

E. Packaging and Testing.

The packaging and testing of devices is probably the greatest challenge facing the MEMS industry. As previously described, MEMS packaging presents unique problems compared to traditional IC packaging in that a MEMS package typically must provide protection from an operating environment as well as enable access to it. Currently, there is no generic MEMS packaging solution, with each device requiring a specialized format. Consequently, packaging is the most expensive fabrication step and often makes up 90% (or more) of the final cost of a MEMS device.

F. Education and Training.

The complexity and interdisciplinary nature of MEMS require educated and well-trained scientists and engineers from a diversity of fields and backgrounds. The current numbers of qualified MEMS-specific personnel is relatively small and certainly lower than present industry demand. Education at graduate level is usually necessary and although the number of universities offering MEMS-based degrees is increasing, gaining knowledge is an expensive and time-consuming process. Therefore, in order to match the projected need for these MEMS scientists and engineers, an efficient and lower cost education methodology is necessary. One approach, for example, is industry-led (or driven) academic research centers offering technology-specific programmers with commercial integration, training and technology transfer. The challenges are shown in fig 7.

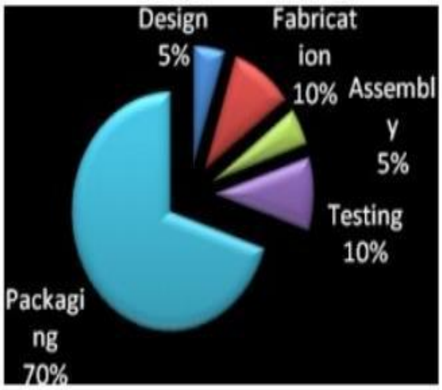

Fig7. Challenges in MEMS

IV. CONCLUSIONS

The potential exists for MEMS to establish a second technological revolution of miniaturization that may create an industry that exceeds the IC industry in both size and impact on society. Micromachining and MEMS technologies are powerful tools for enabling the miniaturization of sensors, actuators and systems. In particular, batch fabrication techniques promise to reduce the cost of MEMS, particularly those produced in high volumes. Reductions in cost and increases in performance of micro sensors, micro actuators and Microsystems will enable an unprecedented level of quantification and control of our physical world. Although the development of commercially successful micro sensors is generally far ahead of the development of micro actuators and micro systems, there is an increasing demand for sophisticated and robust micro actuators and micro systems. The miniaturization of a complete micro system represents one of the greatest challenges to the field of MEMS. Reducing the cost and size of high-performance sensors and actuators can improve the cost performance of macroscopic systems, but the miniaturization of entire high-performance systems can result in radically new possibilities and benefits to society.

Acknowledgment

The authors thanks the Management and Principal of Mahatma Gandhi Institute of Technology, Hyderabad for encouraging and carry out this work.

References

1) MEMS by N.P.Mahalik Tata McGraw-Hill Education Pvt. Ltd 2007

2) MEMS and Microsystems by Tai-Ran Hsu Tata McGraw-Hill Education Pvt. Ltd., 2002

3) Scaling issues and Design of MEMS by S.Bagilo, S.Castorina & N.Sivalli

4) Nexus Market Analysis for MEMS and Microsystems III, 2005 - 2009

5) Think Small!, issue 2, volume 2, July 2007, Wicht Technologie Consulting

6) Lab-on-Chip and Microfluidics Technologies' Capability to Reduce Costs and Time-to-Market Drive Uptake in Drug Development and Clinical Diagnostics, Frost & Sullivan, July 2007

7) Foundries for MST/MEMS – Worldwide-, November 2006 enablingMNT, www.enablingMNT.com

8) Smith, J.H. et. al., Embedded Micromechanical Devices for the Monolithic Integration of MEMS with CMOS, Proc. 1995 IEDM, pp. 609-612

9) Rewards and Risks of Moving into New Applications: Case Study Accelerometers, Henne van Heeren, Jeremie Bouchaud, Richard Dixon and Patric Salomon, MSTnews, February 2007

10) 2005 Electromechanical Switches – Global Market Demand Analysis. www.vdc-corp.com

11) Emerging Markets for Microfluidic Applications, Yole Developpement, June 2007

12) MEMS in Medicine, Ken Gilleo, www.et-trends.com

13) Diagnostic Report 2007, Cambridge Consultants, www.cambridgeconsultants.com B. Warneke, M. Last, B. Liebowitz, K.S.J. Pister. "Smart Dust: Communication with a Cubic-Millimeter Computer", IEEE Computer, January 2001.

14) R. Yeh, S. Hollar, K.S.J. Pister. "Single Mask, Large Displacement Electrostatic Linear Inchworm Motors"

15) J.M. Kahn, R.H. Katz, K.S.J. Pister. "Emerging Challenges: Mobile Networking for 'Smart Dust'", June 2000.