MICRO ELECTRO MECHANICAL SYSTEMS; AN OVERVIEW

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Abstract: MEMS has been identified as one of the most promising technologies for the 21st Century and has the potential to revolutionize both industrial and consumer products by combining silicon-based microelectronics with micromachining technology. Its techniques and micro system-based devices have the potential to dramatically affect of all of our lives and the way we live. MEMS are a process technology used to create tiny integrated devices or systems that combine mechanical and electrical components. They are fabricated using integrated circuit (IC) batch processing techniques and can range in size from a few micrometers to millimeters. These devices have the ability to sense, control and actuate on the micro scale, and generate effects on the macro scale. The interdisciplinary nature of MEMS utilizes design, engineering and manufacturing expertise from a wide and diverse range of technical areas including integrated circuit fabrication technology, mechanical engineering, materials science, electrical engineering, chemistry and chemical engineering, as well as fluid engineering, optics, instrumentation and packaging. This report deals with the field of micro-electromechanical systems and its applications .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, actuators, sensors

I. Introduction

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 1.

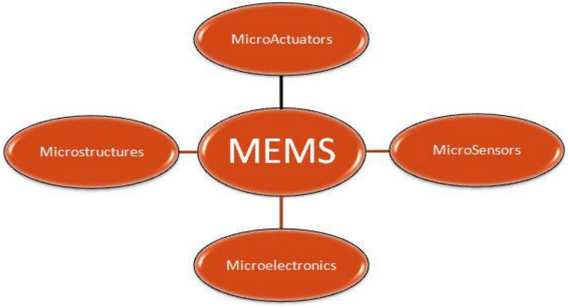

Figure1. Schematic illustration of MEMS components

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 2.

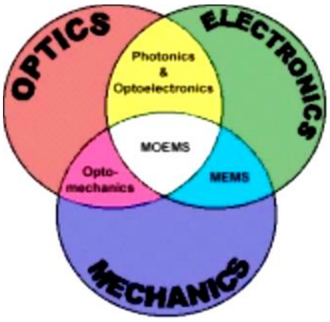

Figure 2. Classifications of Microsystems technology

MEMS devices can be classified into two categories, mainly sensors and actuators. Sensors are non-intrusive while actuators modify the environment.

II. Fabrication Techniques

Materials for MEMS manufacturing

The fabrication of MEMS evolved from the process technology in semiconductor device fabrication, i.e. the basic techniques are deposition of material layers, patterning by photolithography and etching to produce the required shapes.

Silicon

Silicon is the material used to create most integrated circuits used in consumer electronics in the modern industry. The economies of scale, ready availability of inexpensive high-quality materials, and ability to incorporate electronic functionality make silicon attractive for a wide variety of MEMS applications. Silicon also has significant advantages engendered through its material properties. In single crystal form, silicon is an almost perfect Hookean material, meaning that when it is flexed there is virtually no hysteresis and hence almost no energy dissipation. As well as making for highly repeatable motion, this also makes silicon very reliable as it suffers very little fatigue and can have service lifetimes in the range of billions to trillions of cycles without breaking.

Polymers

Even though the electronics industry provides an economy of scale for the silicon industry, crystalline silicon is still a complex and relatively expensive material to produce. Polymers on the other hand can be produced in huge volumes, with a great variety of material characteristics. MEMS devices can be made from polymers by processes such as injection molding, embossing or stereo lithography and are especially well suited to micro fluidic applications such as disposable blood testing cartridges.

Metals

Metals can also be used to create MEMS elements. While metals do not have some of the advantages displayed by silicon in terms of mechanical properties, when used within their limitations, metals can exhibit very high degrees of reliability. Metals can be deposited by electroplating, evaporation, and sputtering processes. Commonly used metals include gold, nickel, aluminium, copper, chromium, titanium, tungsten, platinum, and silver.

Ceramics

The nitrides of silicon, aluminum and titanium as well as silicon carbide and other ceramics are increasingly applied in MEMS fabrication due to advantageous combinations of material properties. Moreover, the high resistance of TiN against biocorrosion qualifies the material for applications in biogenic environments and in biosensors.

MEMS basic processes :

Deposition processes

one of the basic building blocks in MEMS processing is the ability to deposit thin films of material with a thickness anywhere between a few nanometres to about 100 micrometres. There are two types of deposition processes, as follows.

Physical deposition

Physical vapor deposition ("PVD") consists of a process in which a material is removed from a target, and deposited on a surface. Techniques to do this include the process of sputtering, in which an ion beam liberates atoms from a target, allowing them to move through the intervening space and deposit on the desired substrate, and evaporation, in which a material is evaporated from a target using either heat (thermal evaporation) or an electron beam (e-beam evaporation) in a vacuum system.

Chemical deposition

Chemical deposition techniques include chemical vapor deposition ("CVD"), in which a stream of source gas reacts on the substrate to grow the material desired. This can be further divided into categories depending on the details of the technique, for example, LPCVD (Low Pressure chemical vapor deposition) and PECVD (Plasma-enhanced chemical vapor deposition).Oxide films can also be grown by the technique of thermal oxidation, in which the (typically silicon) wafer is exposed to oxygen and/or steam, to grow a thin surface layer of silicon dioxide.

Lithography

Lithography in MEMS context is typically the transfer of a pattern into a photosensitive material by selective exposure to a radiation source such as light. A photosensitive material is a material that experiences a change in its physical properties when exposed to a radiation source. If a photosensitive material is selectively exposed to radiation (e.g. by masking some of the radiation) the pattern of the radiation on the material is transferred to the material exposed, as the properties of the exposed and unexposed regions differs. This exposed region can then be removed or treated providing a mask for the underlying substrate. Photolithography is typically used with metal or other thin film deposition, wet and dry etching.

Etching processes

There are two basic categories of etching processes: wet etching and dry etching. In the former, the material is dissolved when immersed in a chemical solution. In the latter, the material is sputtered or dissolved using reactive ions or a vapor phase etchant.

Wet etching

Wet chemical etching consists in selective removal of material by dipping a substrate into a solution that dissolves it. The chemical nature of this etching process provides a good selectivity, which means the etching rate of the target material is considerably higher than the mask material if selected carefully.

Dry etching

Dry etching is a removal of material, typically a masked pattern of semiconductor material, by exposing the material to a bombardment of ions that dislodge portions of the material from the exposed surface. A common type of dry etching is reactive-ion etching. Unlike with many of the wet chemical etchants used in wet etching, the dry etching process typically etches directionally or an isotropic ally.

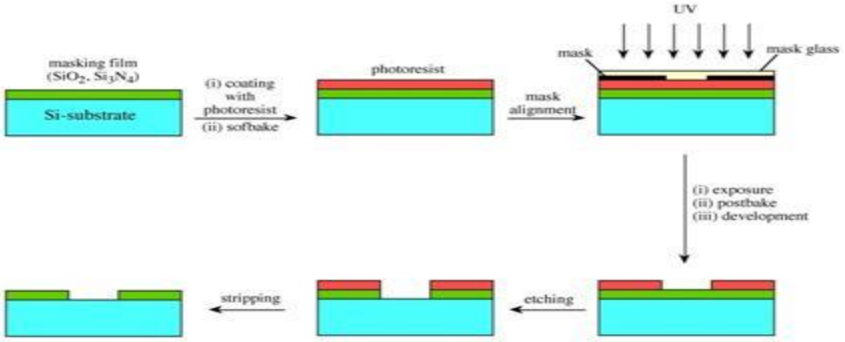

Fig 3.Bulk Micromachining Technique Involving Photolithography

- **Step 1:**The first step involves the circuit design and drawing of the circuit either on a paper or on using software like PSpice or Proteus.
- **Step 2**: The second step involves simulation of the circuit and modeling using CAD(Computer Aided Design). CAD is used to design the photolithographic mask which consists of the glass plate coated with chromium pattern.
- **Step 3**: The third step involves photolithography. In this step, a thin film of insulating material like Silicon Dioxide is coated over the silicon substrate and over this a organic layer, sensitive to ultra violet rays is deposited using spin coating technique. The photolithographic mask is then placed in contact with the organic layer. The whole wafer is then subjected to UV radiation, allowing the pattern mask to be transferred to the organic layer. The radiation either strengthens the photoresist or weakens it. The uncovered oxide on the exposed photoresist is removed using Hydrochloric acid. The remaining photoresist is removed using hot Sulphuric acid and the resultant is an oxide pattern on the substrate, which is used as a mask.
- **Step 4**: The fourth step involves removal of the unused silicon or etching. It involves removal of a bulk of the substrate either using wet etching or dry etching. In wet etching the substrate is immersed in a liquid solution of a chemical etchant, which etches out or removes the exposed substrate either equally in all directions(isotropic etchant) or in a particular direction(anisotropic etchant). Popularly used etchants are HNA (Hydrofluoric acid, Nitric acid and Acetic acid) and KOH(Potassium Hydroxide).
- **Step 5**: The fifth step involves the joining of two or more wafers to produce a multi layered wafer or a 3 D structure. It can be done using fusion bonding which involves direct bonding between the layers or using anodic bonding.
- **Step 6**: The 6th step involves the assembling and integrating the MEMs device on the single silicon chip.
- **Step 7**: The 7th step involves packaging of the whole assembly to ensure protection from outer environment, proper connection to the environment, minimum electrical interference. Commonly used packages are metal can package and ceramic window package. The chips are bonded to the surface either using wire bonding technique or using flip chip technology where the chips are bonded to the surface using an adhesive material which melts on heating, forming electrical connections between the chip and the substrate.

III. Applications

Micro sensors are useful because of their small physical size which allows them to be less invasive. Micro actuators are useful because the amount of work they perform on the environment is also very small, and therefore it can be very precise. Some typical examples of MEMS technology are polysilicon resonator transducers, high aspect ratio electrostatic resonator, magnetic micro motors, precision engineered gears, etc. MEMS are already in wide use in the automotive industry, and are beginning to penetrate other industries as well, such as Nation Defense, etc. For example, MEMS are utilized for engine oil pressure, vacuum pressure, fuel injection pressure, transmission fluid pressure, ABS line pressure, tire pressure, stored airbag pressure, various temperature throughout an automobile, active suspension systems, etc. MEMS accelerometers can also be used to trigger airbags or lock seat belts in the event of an accident; it has been shown that the cost per sensor and the failure rate is dramatically reduced when it is built on the micro scale rather than on the macro scale.

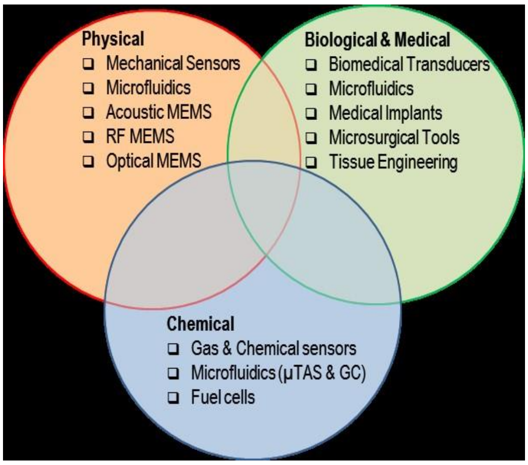

Fig 3. MEMS applications in various functional domains.

There are plenty of applications for MEMS. As a breakthrough technology, MEMS is building 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.

IV. The Future of MEMS

Industry Challenges

Some of the major challenges facing the MEMS industry include:
i) **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.
ii) **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
iii) **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.
v) **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

V. 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.

References

1. Nexus Market Analysis for MEMS and Microsystems III, 2005 - 2009
2. Think Small!, issue 2, volume 2, July 2007, Wicht Technologie Consulting

3. 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
4. Foundries for MST/MEMS – Worldwide-, November 2006 enablingMNT, www.enablingMNT.com
5. Smith, J.H. et. al., Embedded Micromechanical Devices for the Monolithic Integration of MEMS with CMOS, Proc. 1995 IEDM, pp. 609-612
6. Rewards and Risks of Moving into New Applications: Case Study Accelerometers, Henne van Heeren, Jeremie Bouchaud, Richard Dixon and Patric Salomon, MSTnews, February 2007
7. 2005 Electromechanical Switches – Global Market Demand Analysis. www.vdc-corp.com
8. Emerging Markets for Microfluidic Applications, Yole Developpement, June 2007
9. MEMS in Medicine, Ken Gilleo, www.et-trends.com
10. 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.
11. R. Yeh, S. Hollar, K.S.J. Pister. “Single Mask, Large Displacement Electrostatic Linear Inchworm Motors”
12. J.M. Kahn, R.H. Katz, K.S.J. Pister. “Emerging Challenges: Mobile Networking for ‘Smart Dust’”, June 2000.