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Micro-Electro-Mechanical-Systems (MEMS) Technology

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ABSTRACT

Over the last decade Micro-Electro-Mechanical Systems (MEMS) have evoked great interest in the scientific and engineering communities. They are formed by integration of electronic and mechanical components at micron level. They have several substantive advantages: orders of magnitude smaller size, better performance than other solutions, possibilities for batch fabrication and cost-effective integration with electronics and potentially large reduction in power consumption, etc. This paper will give an introduction to these exciting developments of MEMS, the fabrication technology used and applications in various fields.

Keywords: Microelectronics, Micromachining, Miniaturization, Sensors, Actuators.

INTRODUCTION

MEMS stands for Micro-electromechanical systems, a manufacturing technology that enables the development of electromechanical systems using batch fabrication techniques similar to those used in integrated circuit (IC) design [**1**]. They can range in size from micrometers to millimeters. Investing engineered systems with superior capabilities to sense and act is the driving force for the development of MEMS [**2**].

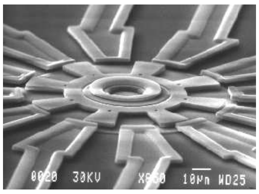


Fig.1 A Rotor of a machine fabricated using MEMS

These systems can sense, control and actuate on the micro scale, and function individually or in arrays to generate effects on the macro scale. MEMS integrate mechanical elements, sensors, actuators and electronics on a silicon substrate using a process technology called micro fabrication [**3**]. It combines conventional semiconductor electronics with beams, gears, levers, switches, sensors, accelerometers, diaphragms, and heat controllers, all of them microscopic in size and for this microelectronics forms the basis. MEMS technologies make devices ranging in size from a dozen millimetres to a dozen microns. For example, MEMS technology has enabled electrically-driven motors smaller than the diameter of a human hair (about 80 (m) to be realized. Thus, MEMS technology lets scientists and engineers build things that have been impossible or prohibitively expensive with other technologies [**4**]. MEMS is not about any one single application or device, nor is it defined by a single fabrication process or limited to a few materials MEMS is a fabrication approach that conveys the advantages of miniaturization, multiple components and microelectronics to the design and construction of integrated electro-mechanical systems.

1. How MEMS work?

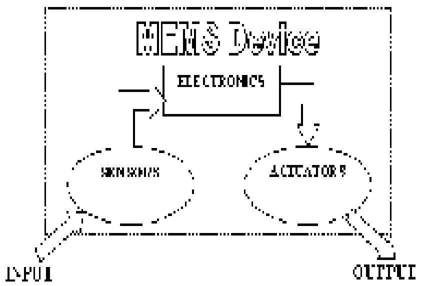


Fig.2 MEMS functional view

The sensors gather information by measuring mechanical, thermal, biological, chemical, magnetic and optical signals from the environment. The microelectronic ICs act as the decision-making piece of the system, by processing the information given by the sensors. Finally, the actuators help the system respond by moving, pumping, filtering or somehow controlling the surrounding environment to achieve its purpose.

2. Manufacturing process

MEMS is a manufacturing technology; that is a new way of making complex Electro mechanical systems [**5**]. This new manufacturing technology has several distinct advantages. First, MEMS is an extremely diverse technology that potentially could significantly impact every category of commercial and military products. Second, it blurs the distinction between complex mechanical systems and integrated circuit electronics. MEMS manufacturing involves the repetitive process of designing, fabrication, packaging and testing, as shown in Fig.

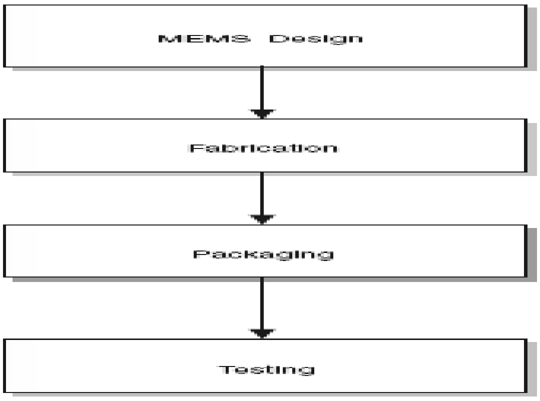


Fig.3 MEMS manufacturing process

(A) Design:
There are software packages available for the design and simulation of MEMS devices.

(B) Fabrication:
The micromechanical components are fabricated using compatible "micromachining" processes. MEMS promise to revolutionize nearly every product category by bringing together silicon-based microelectronics with micromachining technology. This makes possible the realization of complete systems-on-a-chip.

(C) Packaging:
MEMS packaging is an application-specific task. It accounts for the largest fraction of the cost of the MEMS device. Packaging should avoid transferring mechanical strain, heat, pressure, etc. to the device in the package. MEMS introduce new interfaces, processes and materials foreign to the IC packaging industry.

(D) Testing:
The testing of MEMS devices is more complex than that of ICs because of the integrated electronic and mechanical character of MEMS. Since MEMS devices are manufactured using batch fabrication techniques, similar to ICs, unprecedented levels of functionality, reliability and sophistication can be placed on a small silicon chip at a relatively low cost.

3. Characteristics of MEMS Fabrication Technologies

Regardless of the fabrication process used, all MEMS fabrication approaches share three key *characteristics*:

(A) ***Miniaturization.***
Small, light structures yield devices with relatively high resonant frequencies, which in turn produce sensors and actuators with higher operating frequencies and bandwidths. Thermal time

constants, the rate at which structures absorb and release heat, are shorter for smaller, less massive structures.

***(B) Multiplicity*.**
Multiplicity or the Batch-fabrication inherent in photolithographic-based MEMS processing, provides many advantages to electromechanical devices and systems. We can fabricate 10,000 or a million components as easily and quickly as we can make one. This batch fabrication approach is critical to reducing the device's unit cost. Additionally, multiplicity provides the flexibility necessary to design massively parallel, interconnected electromechanical systems.

***(C) Microelectronics*.**
Integrated microelectronics gives MEMS their intelligence and allows closed-loop feedback systems, localized signal conditioning, and the control of massively parallel actuator arrays. Moreover, there is considerable investment in microelectronics materials, processing, and expertise. Because microelectronics is a key part of MEMS, it will be easier and faster to develop MEMS devices, as well as promote their acceptance by systems designers and integrators.

4. Fabrication Of MEMS

Micro engineering refers to the technologies and practice of making three dimensional structures and devices with dimensions in the order of micrometers. The two constructional technologies of micro engineering are microelectronics and micromachining. Microelectronics, producing electronic circuitry on silicon chips, is a very well developed technology [**6**]. Micromachining is the name for the techniques used to produce the structures and moving parts of micro engineered devices.
One of the main goals of Micro engineering is to be able to integrate microelectronic circuitry into micro machined structures, to produce completely integrated systems (Microsystems). Such systems could have the same advantages of low cost, reliability and small size as silicon chips produced in the microelectronics industry [**7**].

Basic Micromachining techniques:
There are three basic techniques associated with silicon micromachining. They are Bulk micromachining ,Surface micromachining and High aspect ratio micromachining.

(A) Bulk Micromachining:
It is applied to a variety of etching procedures that selectively remove material, typically with a chemical enchants whose etching properties are dependent on the crystallographic structure of bulk material.

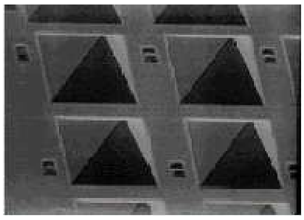


Fig.4 WET ETCHING is used

Fig.5 DRY ETCHING is used

(B) Surface Micromachining:

It starts with wafer of material ,but unlike Bulk Micromachining where the wafer itself serves as the stock from which material is removed to define mechanical structures , in surface micromachining is the substrate—the working surface—on which multiple, alternating layers of structural and sacrificial layers are deposited and etched. Because of the laminated structural and sacrificial material layers the etching of material done by a process that is insensitive to crystalline structure, surface micromachining enables the fabrication of free-form complex and multi-component integrated electro mechanical structures, liberating the MEMS designer to envision and build devices and systems that are impossible to realize with bulk process. More than any other factor, it is surface micromachining that has ignited and is at the heart of the current scientific and commercial scientific activity in MEMS.

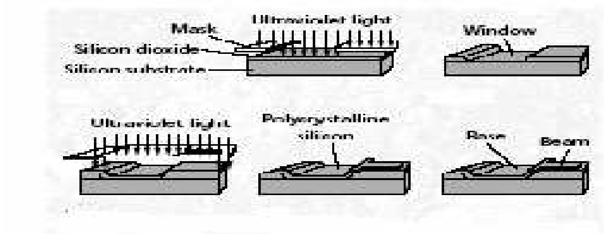


Fig.6 Simple Surface micromachining fabrication

(C) High-aspect ratio Micromachining:

It is an even newer machining technique, developed to allow the fabrication of thick, precision high-aspect ratio MEMS structures. Bulk micro machined structures are limited to thickness of a few hundred microns. Surface micro machined structures, with their deposited structural films are much thinner, usually limited to thickness of no more than 5 to 10 microns. This uses photolithographic process, but the photo resist layers are hundreds of microns to centimeters thick rather than their 1 to 2 microns typical in bulk and surface micromachining.

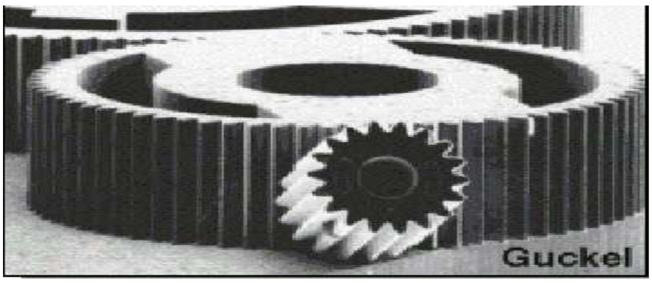


Fig.7 High-aspect ratio micromachined device

5. APPLICATIONS OF MEMS [8]

(A) Telecommunications:

Telecommunications has a broad array of applications, from micro relays for line card applications to complex multi frequency tunable systems for wireless communications. The integrated circuit industry is heading toward system on a chip (SOC), which seeks to integrate complete functionality on a single silicon substrate.

(B) Applications of MEMS in Communications Satellites:
MEMS ***offer*** significant benefits for future satellite systems since they can realize various electrical and mechanical functions in a fraction of the size, weight, **and** power consumption of corresponding traditional "macro" systems. This makes these devices quite attractive in space applications, especially in commercial communications satellites, which ***are*** constantly **driven by** increased capabilities, high levels of integration, miniaturization and cost reductions. Several applications of MEMS in satellite platforms ***are*** presently under consideration. This includes micro sensors, micro actuators, micro heat pipes for thermal management, propulsion, active conformable surfaces, etc.

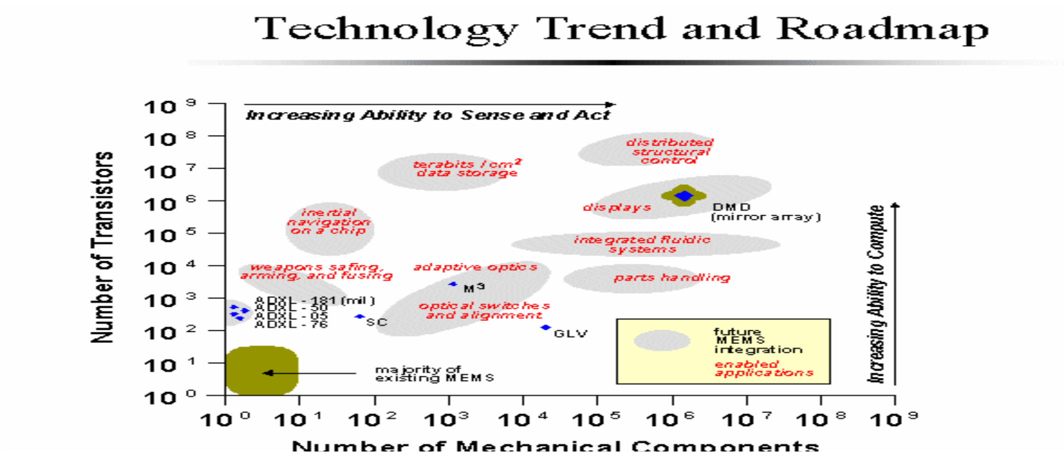
Applications of MEMS technology in microwave components **and** subsystems ***ore*** growing very rapidly.

Automotive:
For the past six years, the automotive industry has used MEMS to sense and control a car's relationship to its environment, most notably to sense acceleration.

(C) Healthcare:
Micro fabricated silicon pressure sensors for blood pressure monitoring, Respirators, Kidney dialysis equipment are some of the applications of MEMS in this field.

(D) General Applications:
Pressure, temperature, chemical and vibration sensors, Light reflectors Switches Accelerometers (for airbags, pacemakers) , Micro actuators for data storage and read/write heads All-optical switches Storage devices etc…are general applications of MEMS devices.

7. Technology Trends:



The figure is a map of electromechanical integration that we created to trace MEMS developments across application areas. We view the number of transistors as a measure of information processing ability and the number of mechanical components as a measure of the ability to perceive and control the operational environment.

Current challenges:
Fabrication : limited companies
Packaging : application specific
Expertise : interdisciplinary expertise needed for successful technology implementation.
CAD tools : Not yet fully developed

Future trends:
Future MEMS applications will be driven by processes that enable greater functionality through higher levels of electronic-mechanical integration and more mechanical components. These process developments will be paced by the development of: New materials, Device and system design, Fabrication techniques, Packaging/assembly methods, Test and characterization tools etc.

8. Market trends

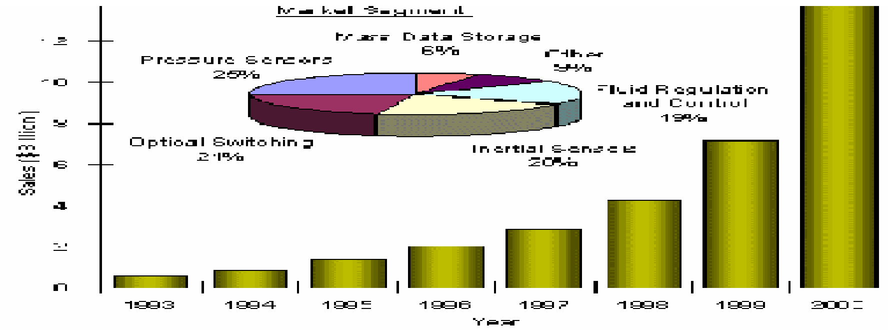


Fig.8 Exponential growth of MEMS market

The MEMS industry has a projected 10-20% annual growth rate, with the potential of a greater than $8 billion market by the year 2001. Due to the enabling nature of MEMS and because of the significant impact they can play on both the commercial and defense markets, both industry and the federal government have taken special interest in seeing growth nurtured in this field [**9**].

CONCLUSION

MEMS technology has already taken root firmly in today's world. It is destined to become a hallmark 21st-century manufacturing technology with numerous and diverse applications. MEMS will have a dramatic impact on everything from aerospace technology to biotechnology. As a breakthrough technology allowing unparalleled synergy between apparently unrelated fields of endeavor such as biology and microelectronics, MEMS is forecasted to have a commercial and defense market growth similar to its parent IC technology. Designing various MEMS models i.e sensors, transducers, accelerometer, Actuators, etc by COMSOL-Multiphysics software are in progress.

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