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Review on Break through MEMS Technology

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ABSTRACT

MEMS - Micro electro mechanical systems. It refers to machines with moving parts smaller than a human hair that contain both electrical and mechanical components on silicon. Also referred to as Microsystems, microstructures, microstructure technology (MST) and mechatronics. Micro electro mechanical Systems (MEMS) have gained acceptance as viable products for many commercial and government applications. This paper gives a brief review of history and components of MEMS. This paper will discuss current and future MEMS applications. It then gives the fabrication processes of MEMS. Further this paper discusses about the MEMS achievements, challenges and requirements. Next it discusses the future form of MEMS. Lastly it concludes saying that MEMS have enough potential 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.

INTRODUCTION

MEMS are typically defined as microscopic devices designed, processed, and used to interact or produce changes within a local environment. A mechanical, electrical, or chemical stimulus can be used to create a mechanical, electrical, or chemical response in a local environment. These smaller, more sophisticated devices that think, act, sense, and communicate are replacing their bulk counterparts in many traditional applications.

Micro-Electro-Mechanical-Systems (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology. These devices replace bulky actuators and sensors with micron scale equivalent that can produce in large quantities by fabrication process used in integrated circuits in photolithography. They reduce cost, bulk, weight and power consumption while increasing performance, production volume and functionality by orders of magnitude.

2. HISTORY OF MEMS:

MEMS are in their most basic forms, diminutive version of traditional electrical and mechanical devices- such as valves, pressure sensors, hinged mirrors, and gears with dimensions measured in microns- manufactured by techniques similar to those used in fabricating microprocessor chip. The first product was developed in the 1960's when accurate hydraulic pressure sensors were needed for aircraft. Such devices were further refined in 1980's were implemented in fuel-injected car engines to monitor intake-manifold pressure. In the late 80's MEMS accelerometer for car airbags were developed as a less expensive, more reliable, and more accurate replacement for a conventional crash sensor.

FIG1: Accelerometer

Taking the spotlight today is optical MEMS (also known as Micro Opto Electro Mechanical System, or MOEMS), primarily micromirrors, which are used as digital light processors in video projectors and as switches in optical network equipment.

FIG 2: MOEMS

As a general rule of thumb, MEMS typically have dimensions ranging from nanometers to centimeters; however, very little has been done with MEMS below one micrometer. On the contrary, recent developments in IC technologies can now mass produce chips with features as small as 0.13 microns; the new Intel Pentium 4 processor running at 2.2 to 2.4 GHz is one such example.

3. COMPONENTS OF MEMS:

MEMS components are categorized in one of six distinct applications. These include:

1) Sensors are a class of MEMS that are designed to sense changes and interact with their environments. These classes of MEMS include chemical, motion, inertia, thermal, and optical sensors.

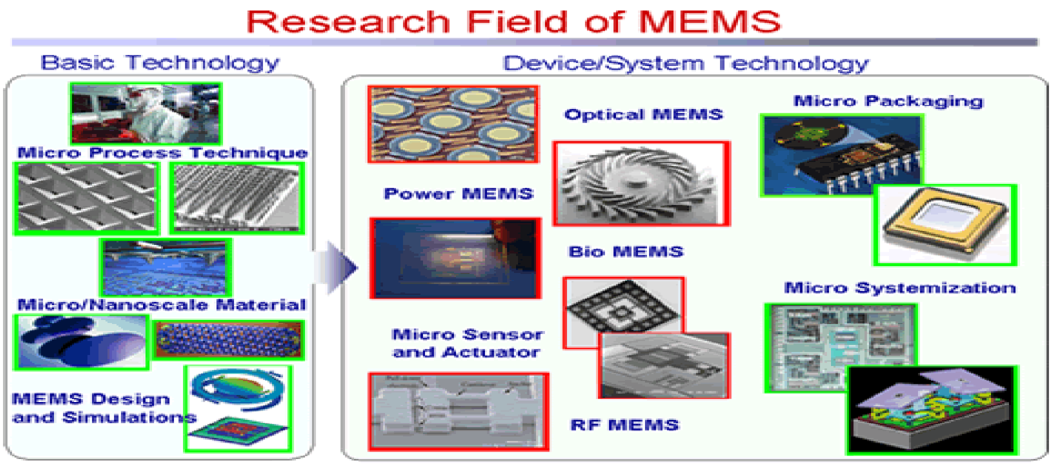
2) Actuators are a group of devices designed to provide power or stimulus to other components or MEMS devices. In MEMS, actuators are either electrostatically or thermally driven.

3) RF MEMS are a class of devices used to switch or transmit high frequency, RF signals. Typical devices include; metal contact switches, shunt switches, tunable capacitors, antennas, etc.

4) Optical MEMS are devices designed to direct, reflect, filter, and/or amplify light. These components include optical switches and reflectors.

5) Microfluidic MEMS are devices designed to interact with fluid-based environments. Devices such as pumps and valves have been designed to move, eject, and mix small volumes of fluid.

6) Bio MEMS are devices that, much like micro fluidic MEMS are designed to interact specifically with biological samples. Devices such as these are designed to interact with proteins, biological cells, medical reagents, etc. and can be used for drug delivery or other in-situ medical analysis.



4. APPLICATIONS:

MEMS devices can be classified into two categories, mainly sensors and actuators. [**1**] Sensors are non-intrusive while actuators modify the environment.

FIG 3: MICROSENSORS

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 ration electrostatic resonator, magnetic micro motors, precision engineered gears, etc. [**2**] MEMS are already in wide use in the automotive industry, and are beginning to penetrate other industries as well, such as Nation Defense etc.

FIG 4: MICRO PUMP

[**3**]One application of MEMS is “Smart Dust”. The goal is to explore the limits on size and the power consumption in autonomous sensor nodes. The size reduction will be a major challenge since the functionality of Smart Dust will require that the nodes have requisite sensing, communication, computing hardware, and power supply all in a volume no more than a few cubic millimeters without sacrificing the performance of the node. With a cubic millimeter volume, using the best available battery technology, the total stored energy is limited to the order of 1 Joule.Energy-optimized microprocessors use roughly 1 nano-Joule per sample. For comparison purposes, Bluetooth radio frequency (RF) communication chips will burn about 100 nano-Joules per bit transmitted; picoradios will be targeting 1 nano- Joules per bit. [**4**] Another application is to make micro-robots using the Smart Dust technology; if we add legs and wings to the already existing Smart Dust, we get micro-robots that can sense, think, communicate, move, and interact with their environment. Micromachining is used to build microactuators and micromechanisms, forming the legs and wings. A crawling micro-robot consumes only tens of microwatts of power generated by solar cells while it can lift over 130 times its own weight.

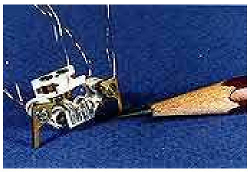


FIG 5: CRAB ROBOT

[**5**]Another application is electrostatic linear inchworm motor. This family of motors is fabricated on Silicon-on-Insulator wafers using only a single mask. [**6**] Although microactuators are less mature than that of microsensors due to the initial lack of appropriate applications and the difficulty to reliably couple the microactuators to the macroscopic world, there quite a few techniques that have evolved. To name a few, there are electrostatic microactuators (a) thermal microactuators ,(b) magnetic microactuators (c) piezoelectric microactuators .Since most microactuators are custom developed for specific applications, no microactuator standards yet exist.[**7**] MEMS technologies is enabling new discoveries in science and engineering such as Polymerase Chain Reaction (PCR) microsystems for DNA amplification and identification, the micromachined Scanning Tunneling Microscopes (STMs), biochips for detection of hazardous chemical and biological agents, microsystems for high-throughput drug screening and selection,

optical switches, valves, RF switches, microrelays, electronic noses,etc. Although the existing market for microsystems is dominated by pressure sensors, strain gauges, inertial sensors, chemical sensors, in vitro diagnostics, infrared imagers and magnetometers, capacitive position detection, thermal sensors, biosensors, there is also a relatively large market segment specializing in recording magnetic heads and inkjet printer heads.

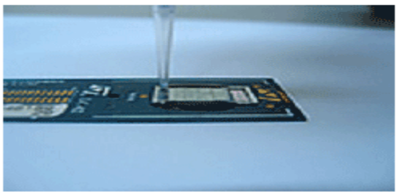


FIG 6: The InCheck Lab-on-a-Chip speeds DNA analysis

[**8**] Communication with the microsystems would be done via a direct connection or a wireless communication link. Another important new application is in fiber optic networks. At the micron level, MEMS-based switches route light from one fiber to another. Such an approach enables a truly photonic (completely light-based) network of voice and data traffic, since switching no longer requires conversion of light signals into digital electronic signals and then back to optical.

5.MEMS FABRICATION PROCESSES :

Typically, a MEMS device is first designed with a Computer Aided Design (CAD) tool.Ideally, the MEMS CAD tool would be capable of rapid solving, mechanical, thermal, electrostatic, magnetic, fluidic, RF, and optical solutions in a coupled fashion. This layout is then sent to a foundry, where the chip is fabricated, a mask-less post-processing release step is performed where sacrificial layers are etched away, allowing the structural layers to move and rotate.

There are two main fabrication classes for manufacturing MEMS devices, namely surface micromachining and bulk micromachining.

Surface micromachining technique is relatively independent of the substrate utilized, and therefore can be easily mixed with other fabrication techniques which modify the substrate first. An example is the fabrication of MEMS on a substrate with embedded control circuitry, in which MEMS technology is integrated with IC technology. This is being used to produce a wide variety of MEMS devices for many different applications. On the other hand, bulk micromachining is a subtractive fabrication technique, which converts the substrate, typically a single-crystal silicon, into the mechanical parts of the MEMS device. Packaging of the device tends to be more difficult, but structures with increased heights are easier to fabricate when compared to surface micromachining. This is because of the substrates can be thicker resulting in relatively thick unsupported devices.

TABLE 1: Examples Of Process Equipments Specific To MEMS

FABRICATON TECHNOLOGY	PROCESS EQUIPMENT
SURFACE MICROMACHINING	Release and drying systems to realize free-standing microstructures
BULK MICROMACHINING	Dry etching systems to produce deep, 2D free-form geometries with vertical sidewalls in substrates Anisotropic wet etching systems with protection for wafer front sides during etching Bonding and aligning systems to join wafers and perform photolithography on the stacked substrates .

ACHIEVEMENT

'A thousand points of light' no longer a metaphor. "**Ambitious plan to give sight to the blind".** The idea, funded by a $9 million, three-year grant from the Department of Energy's Office of Biological and Environmental Research, is to create 1,000 points of light through 1,000 tiny MEMS electrodes. The electrodes will be positioned on the retinas of those blinded by diseases such as age-related macular degeneration and retinitis pigmentosa. These diseases damage rods and cones in the eye that normally convert light to electrical impulses, but leave intact the neural paths to the brain that transport electrical signals. Eventually the input from rods and cones ceases, but 70 to 90 percent of nerve structures set up to receive those inputs remain intact. The plan is to use a tiny camera and radio-frequency transmitter lodged in the frame of a patient's glasses to transmit information and power to modules placed within the eyeball. The modules will be linked to retinal nerves that will send electrical impulses to the brain for processing.

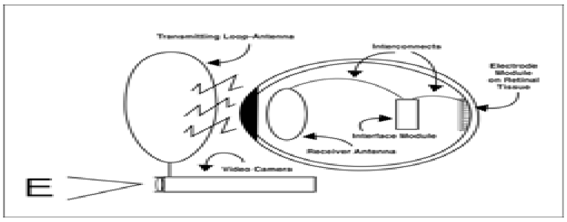


FIG 7: A drawing of retinal prosthesis implant shows the imaging camera at bottom (possibly situated on frame glasses), transmitting power and information via loop antenna to modules within the eyeball.

6. CHALLENGES & REQUIREMENTS:

i)Limited Options: Most of the companies who wish to explore the potential of MEMS have very limited options for prototyping or manufacturing devices, and have no capability or expertise in microfabrication technology. A mechanism giving smaller organization responsive and affordable access to MEMS is essential.

ii)Packaging: MEMS packaging is more challenging than IC packaging due to diversity of MEMS devices and the requirement that many of these devices be in contact with there environment. Most companies find that packaging is the single most expensive and time consuming task in their overall product development program.

iii) Fabrication Knowledge Required: Currently the designer of MEMS device require a high level of fabrication knowledge in order to create a successful design. MEMS devices require a dedicated research effort to find a suitable process sequence for fabricating it.

FUTURE OF MEMS: NEMS

NEMS stands for Nano-Electro-Mechanical-Systems is the technology that is similar to MEMS, however it involves fabrication on the nanometer scale rather than the Micrometer scale. According to Michael Roukes NEMS can be built with masses approaching a few attograms (10-18 grams) and with a cross-section of about 10 Nanometers. Processes such as electron-beam lithography and nanomachining now enable Semiconductor nanostructures to be fabricated below 10 nm. Although the technology exists to create NEMS, there are three principal challenges that must be addressed before. The full potential of NEMS can be realized. First of all, communicating signals from the Nanoscale to the macroscopic world can pose a great challenge. Understanding and Controlling mesoscopic mechanisms are still at the very early stages. Thermal conductance in this regime is quantized, which implies that quantum mechanics places an upper limit on the rate at which energy can be dissipated in small devices by vibrations. Lastly, we do not have the methods for reproducible and routing mass nanofabrication; device Reproducibility is currently very hard and almost unachievable. It is clear that if NEMS are ever to become a reality, cleaner environments and higher precision of Nanofabrication techniques are needed. As we shrink MEMS towards the domain of NEMS, the device physics becomes increasingly dominated by the surfaces. We would expect that extremely small Mechanical devices made from single crystals and ultrahigh-purity heterostructures would contain very few defects; therefore, the energy loses are suppressed and higher Quality factors should be attainable. However, with the Possibility of NEMS, which can move on timescales of a nanosecond or less, the era of the digital electronic age needs to be carefully re-examined.

CONCLUSION

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 microsensors, microactuators and microsystems will enable an unprecedented level of quantification and control of our physical world. Some of the MEMS models are designed by COMSOL Multiphysics are in progress.

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