Review on MEMS Technology

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Abstract: Micro-electromechanical systems is one of the most promising technologies in the field of electronics and mechanical engineering since last decades, which has the potential to revolutionize both industrial and consumer products by combining silicon-based microelectronics with micromachining technology. The optimization techniques and micro system-based tiny devices have the potential to dramatically affect of all of our lives and the way we live. This paper presents a survey on MEMS devices and their operating principles.

Keywords: MEMS, LIGA, pressure sensor, surface micromachining, wafer bonding etc.

1. INTRODUCTION

Microelectromechanical systems (MEMS) is the combination of micro sensors and actuators that can sense its environment and have the ability to respond to the changes in that environment with the help of microcircuit control. The system includes conventional microelectronics packaging, integrating antenna structures for command signals into microelectromechanical structures for desired sensing and actuating functions. It requires micro-power supply, micro-relay, and micro-signal processing units for the proper functioning of the system. The advantages of micro-components are to make the system faster, more reliable, cheaper, and capable of incorporating more complex functions. In the beginning of 1990s, MEMS technology is emerged with the aid of the development of integrated circuit (IC) fabrication processes, where sensors, actuators, and control functions are fabricated on silicon wafer. Since then, remarkable research progresses have been achieved in MEMS under the strong capital promotions from both government and industries[1,2]. Micromachining is used as a fundamental technology for the fabrication of MEMS devices and, in particular, miniaturized sensors and actuators. This technique is used to fabricate such features as clamped beams, membranes, cantilevers, grooves, orifices, springs, gears, suspensions, etc. Bulk micromachinings is the most commonly used method of micromachining, but it is being replaced by surface micromachining that offers the variety of possibility of integrating the machined device with microelectronics that can be patterned and assembled on to the same silicon wafer. Thus the ASICs can be incorporated for the implementation of power supply and signal processing circuitry. It is the efficiency of creating several such complete packages using existing technology that makes this an attractive approach.

II. APPLICATIONS OF MEMS:

i) Airbag sensors in Automotive

The first and most practical applications of MEMS is the automotive airbag sensors. They are in widespread use today in almost all vehicles in the form of a single chip containing a smart sensor, or accelerometer, which measures the rapid deceleration of a vehicle on hitting an object. This will sense the deceleration by means of change in voltage. After sensing, electronic control unit subsequently sends a signal to trigger and explosively fill the airbag. MEMS has enabled the function of ball and tube assembly as used in manual type of airbags to accomplished by integrating an accelerometer and the electronics into a single silicon chip, resulting in a tiny device that can be placed within the steering wheel column and hence reduces the costs(Figures 1 and 2). The accelerometer is either capacitive or piezoresistive device consisting of a suspended pendulum proof mass/plate assembly. As acceleration acts on the proof mass, micromachined capacitive or piezoresistive plates sense a change in acceleration from the deflection of the plates.

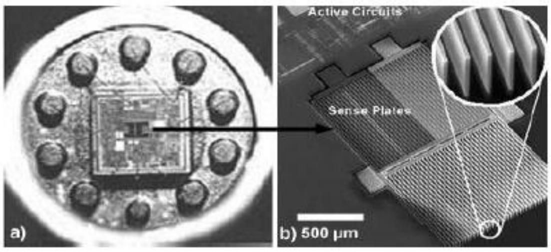
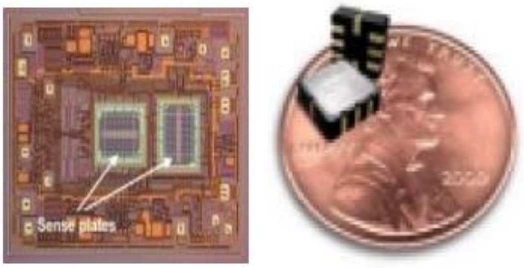


Figure (1) The first commercial accelerometer from Analog Devices (1990); its size is less than 1 cm 2 (left) [12], and (b) capacitive sense plates, 60 microns deep (right) [13].

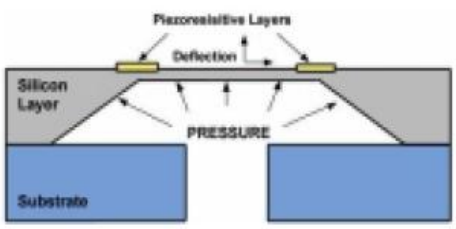


Figure(2). Modern day MEMS accelerometer (left), and the fully packaged device (right) [12].

The practical example of this success is BMW 740i car has over 70 MEMS devices including anti-lock braking systems(ABS), active suspension, appliance and navigation control systems, vibration monitoring, fuel sensors, noise reduction, rollover detection, seatbelt restraint and tensioning etc. [1, 2]

ii) Bio-Medical pressure sensor

Bio medical pressure sensor is the another good example of successful MEMS application for the monitoring of blood pressure. The sensors of this are connecting to a patient's intravenous (IV) line and monitor the blood pressure through the IV solution. For a fraction of their cost ($10), they replace the early external blood pressure monitoring system that costs over $600 and had to be sterilized and recalibrated every time when reuse. These expensive devices measure blood pressure with a saline-filled tube and diaphragm arrangement that has to be connected to an artery with a needle.



For this purpose a disposable sensor consists of silicon substrate which is etched to produce a membrane is used and is bonded to a substrate.

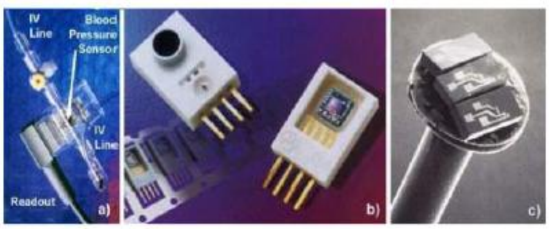


Figure (3) Disposable blood pressure sensor connected to an IV line ,(b) disposable blood pressure sensors (as shipped) , and (c) intracardial catheter-tip sensors for monitoring blood pressure during cardiac catheterisation, shown on the head of a pin.

A layer of piezoresistive material is applied on the membrane surface near the edges to convert the mechanical stresses into an electrical voltage. Pressure corresponds to deflection of the membrane. The sensing element is mounted on a plastic or ceramic base with a plastic cap over it, designed to fit into a manufacturer's housing (Figure 3). A gel is used to separate the saline solution from the sensing element.

iii) Inkjet printer head

Inkjet printer head is another most successful MEMS applications, superseding even automotive and medical pressure sensors. It uses a series of nozzles to spray drops of ink directly on to a printing medium. The droplets of ink are formed either thermally or piezoelectrically, depending on the type of inkjet printer. The first inkjet printer was invented in 1979 by Hewlett-Packard, the thermal expansion of ink vapour is used in MEMS thermal inkjet printer head technology.

An array of tiny resistors known as heaters are placed within the printer head. These resistors can be fired using microprocessor control with electronic pulses of a few milliseconds (usually less than 3 microseconds). The ink flows over each resistor, which then fired, heat up at 100 million o^{C}/ second, vaporizing the ink to form a bubble. Some of the ink is pushed out from a nozzle within a nozzle plate, when the bubble expands, landing on the paper and solidifying almost instantaneously. A vacuum is created which pulls more ink into the print head from the reservoir in the cartridge when the bubble is collapsed. It is worth noting there are no moving parts in this system illustrating that not all MEMS devices are mechanical.

iv) Overhead projection display

Digital Micromirror Device (DMD) is the latest MEMS devices used for a variety of display applications made by Texas Instruments. This devices contains over a million of tiny pixel-mirrors each of sizes 16 µm by 16 µm which able to rotates by ±10o, over 1000 times per second (Figure 4). The light from a projection source impinges on the pupil of the lens (or mirror) and is reflected brightly onto a projection screen. These are used for displays of PC projectors, high definition televisions (HDTV's) and in digital cinemas where traditional liquid crystal technology cannot compete. MEMS has enabled the micromirrors to be only 1 µm apart, resulting in an image taking up a larger percentage (89 percent) of space on the DMD chip's reflective surface, as compared to a typical LCD (12 to 50 percent). This will help to reduce the pixelation and produces an overall sharper and brighter image. Today over 30 manufacturers use the DMD and over 500,000 systems have been shipped.

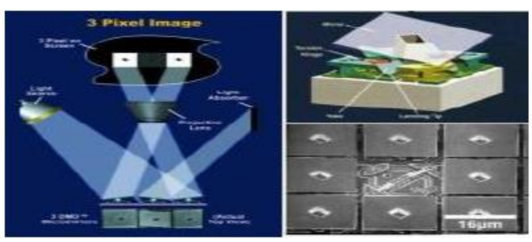


Figure 4. MEMS Digital Micromirror Device [17].

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III. MEMS FABRICATION METHODS :

Classification of MEMS fall into three class; bulk micromachining, surface micromachining and high-aspect-ratio micromachining (HARM), which includes technology such as LIGA (a German acronym from Lithographie, Galvanoformung, Abformung translated as lithography, electroforming and moulding).

3.1 Bulk Micromachining of Silicon

It is one of the most popular silicon micromachining technologies. It emerged in the early 1960s and has been used since then in the fabrication of different microstructures. The name comes from the fact that this type of micromachining is used to realize micromechanical structures within the bulk of a single-crystal silicon wafer by selectively removing ('etching') wafer material. The microstructures fabricated using bulk micromachining may cover the thickness range from submicron to full wafer thickness (200–500 μ m), and the lateral size range from submicron to the lateral dimensions of a full wafer. Bulk micromachining technique allows to selectively remove significant amounts of silicon from a substrate to form membranes on one side of a wafer, a variety of trenches, holes, or other structures (Figure 1.1).

3.2 Surface Micromachining of Silicon

Surface micromachining does not shape the bulk silicon but instead builds structures on the surface of the silicon by depositing thin films of 'sacrificial layers' and 'structural layers' and by removing eventually the sacrificial layers to release the mechanical structures. The prime advantage of surface-micromachined structures is their easy integration with IC components, because the wafer is also the working area for IC elements.

IV. LIGA PROCESS

MEMS generally require complex microstructures that are thick and three-dimensional [2]. Therefore, many microfabrication technologies have been developed to achieve high-aspect-ratio (height-to-width) and 3D devices. LIGA process is one of those microfabrications. LIGA is a German acronym for Lithographie, Galvanoformung, Abformung (lithography, galvanoforming, molding). It was developed by the research Center Karlsruhe in the early 1980s in Germany using X-ray lithography for mask exposure, galvanoforming to form the metallic parts, and molding to produce microparts with plastic, metal, ceramics, or their combinations [5]. A schematic diagram of the LIGA process is shown in Figure 5. With the LIGA process, microstructure's height can be up to hundreds of microns to minimeter scale, while the lateral resolution is kept at submicron because of the advanced X-ray lithography. Various materials can be incorporated into LIGA process allowing electric, magnetic, piezoelectric, optic, and insulating proper- ties of sensors and actuators with a high-aspect ratio, which are not possible to make with the silicon-based processes. Besides, by combining the sacrificial layer technique and LIGA process, advanced MEMS with moveable microstructures can be built (Figure 5). As we know that complex thick 3D structures are necessary for some advanced MEMS, it means that other 3D-microfabrication processes need to be developed for MEMS.

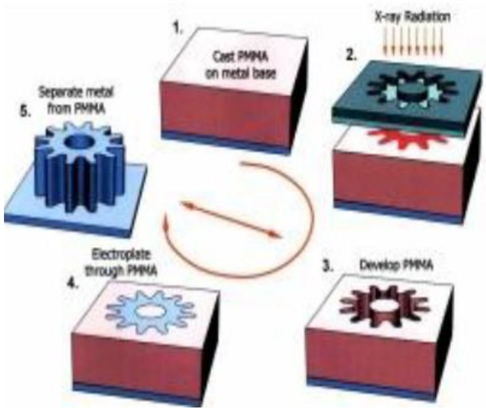

Figure 5. The LIGA process [3].

V. PACKAGING

The proper operation of MEMS devices depends critically upon the 'clean' environment provided by the package and is considered an enabler for the commercialisation of MEMS. Packaging of microsensors presents special problems as part of the sensor requires environmental access while the rest may require protection from environmental conditions and handling.

Although there is no generic package for a MEMS device, the package should: [9]

- provide protection and be robust enough to withstand its operating environment
- allow for environmental access and connections to physical domain (optical fibres, fluid feed lines etc.)
- minimize electrical interference effects from inside and outside the device
- dissipate generated heat and withstand high operating temperatures (where necessary)
- minimize stress from external loading
- handle power from electrical connection leads without signal disruption.

VI. THE FUTURE OF MEMS

7.1 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 commercialisation of MEMS.

ii) Design, Simulation and Modelling.

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 modelling 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 modelling tools are necessary for accurate prediction of MEMS device behaviour.

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.

iv) Standardization.

Due to the relatively low number of commercial MEMS devices and the pace at which the current technology is developing, standardization has been very difficult. To date, high quality control and basic forms of standardization are generally only found at multi-million dollar (or billion dollar) investment facilities. However, in 2000, progress in industry communication and knowledge sharing was made through the formation of a MEMS trade organization.

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 centres offering technology-specific programmes with commercial integration, training and technology transfer.

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