

A SURVEY ON MEMS FABRICATION TECHNOLOGY

Guruprasad B Assistant professor, vidyavikas institute of engineering and technology, Mysuru.

Shwetha M S, M.tech , sri jayachamarajendra college of Engineering, Mysuru.

Abstract- *Microelectronic Mechanical Systems (MEMS) is the technology which enables greater power and supreme complexity in a small, single system. MEMS technology is essentially very micro machines, miniature mechanical devices driven by electricity. MEMS devices combine electronic circuitry with mechanical structures to produce different results. These devices are created with silicon chips using well-established, very-large-scale integration and complementary metal-oxide semiconductor (CMOS) foundry processes. In this paper many fabrication techniques and applications of MEMS are discussed in order to integrate number of operations in a single system.*

Keywords- MEMS, Bulk micromachining, Surface micromachining, High aspect ratio, LIGA.

I. INTRODUCTION

MEMS and nanotechnology are the two terms that deals with microminiaturized objects, which are entirely different. The MEMS technology deals with the inventing devices that are calculated in micrometers, whereas nano technology deals with manipulating atoms at the nanometer level. The one main criterion of MEMS is that there are some elements having some type of mechanical functionality whether or not these elements can move. The term used to define MEMS which varies in different parts of the world. In the United States they are usually called as MEMS, while in other parts of the world they are called “Microsystems Technology” or “micro machined devices”.

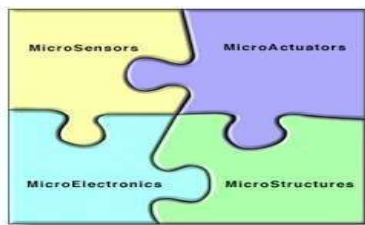


Fig1: components of MEMS

The functional components of MEMS are microstructures, micro sensors, micro actuators, and microelectronics[18]. The most important elements are the microsensors and microactuators. Microsensors and microactuators are categorized as “transducers”, which converts energy from one form to another. Whereas microsensors are the one that converts a measured mechanical signal into an electrical signal. From past few years, many of the researchers and developers have demonstrated large number of microsensors for every possible sensing modality which includes various parameters such as, temperature, pressure, inertial forces, chemical species, magnetic fields, radiation, and many more. Noticeably, many of these micro machined sensors have excellently demonstrated performances exceeding those of their macroscale counterparts. For example, the micromachined version of a pressure transducer usually outperforms a pressure sensor made using the most accurate macroscale level machining techniques. There is not only the performance of MEMS devices exceptional, but their method of production leverages the same batch fabrication techniques utilised in the IC industry – that can translate into low per-device production costs, and many other advantages. It is not only possible to achieve stellar device performance, but to do so at a relatively low cost level. Not surprisingly, silicon based discrete microsensors were quickly commercially exploited and the markets for these devices continue to grow at an exponential rate.

The existing literature contains several reviews of important technologies for the fabrication of MEMS (by Bruce K et al 7, Hongyi Yang et al 8 and Kenichi Takahata 9). Several review articles on fabrication technologies for MEMS have also been published 20-25.

In contrast to previous work, the present paper provides a comprehensive, up-to-date overview and comparison of the available technologies for fabrication of MEMS. Established and emerging technologies for the fabrication of MEMS are reviewed, analyzed and categorized in a coherent manner, and the applications of MEMS products is discussed.

MEMS Fabrication Techniques

MEMS fabrication is an exciting endeavor due to the customized nature of process technologies and the extremely diversity of processing capabilities. Nowadays, many fabrication techniques are used. Basically to fabricate a MEMS device more than one of these techniques is used[18]. The three important features that must be considered in MEMS fabrication techniques are:

1. Miniaturization – The miniaturization allows the fabrication of compact and quick response devices. It is one of the trend to manufacture ever smaller mechanical, optical and electronic products and devices. It is also way to improve the heat and mass transfer by two combined effects. One of them is the diffusion distance within the reactor is much lower and another effect is the interfacial area per unit reactor volume is larger. The miniaturization of mobile phones, computers and vehicle engine downsizing are some of the examples.

Miniaturization of the physical systems is not only just scaling down device components in sizes. Some physical systems either cannot be scaled down easily, or cannot be scaled down at all. Thus for an engineer, Scaling laws become the very first thing that would do in the design of MEMS and Microsystems. One of the types of Scaling law is, Scaling in Geometry i.e., the scaling of physical size of objects and the second law is scaling of Phenomenological Behaviour i.e., scaling of both size and material characterizations.

2. Multiplicity – The multiplicity is the ability of the fabrication techniques, inherent in semiconductor processes, that results in thousands or millions of units concurrently. Multiplicity also called as batch fabrication inherent in photolithographic-based MEMS processing, is as important as miniaturization. It provides two major advantages to electromechanical devices and systems. Multiplicity makes it possible to fabricate ten thousand or a million MEMS components as easily and quickly as one. The second, equally important advantage of multiplicity is the flexibility in the design of massively parallel, combined with electromechanical systems. This multiplicity characteristic has already been exploited in the development and demonstration of a digital micromirror display. In an array about the size of two postage stamps, over a million mirrors-each the size of a white blood cell-collectively generate a complete, high-resolution video image.

3. Microelectronics- The microelectronics refers to provide the merger of sensors, actuators and logic in a unit, so that feedback (intelligent) mechanisms can be implements. Thus, either the miniaturization or the multiplicity characteristics of MEMS could not be completely exploited without microelectronics. The microelectronics with MEMS devices results in the latter with intelligence and allows closed-loop feedback systems, localized signal actuator arrays. The remarkable investment that has been

made into microelectronics materials and processing, and the expertise built up in this field, is helping the development of MEMS devices.

To fabricate MEMS combine the first two features, both inherited from the semiconductor IC(integrated circuit) domain such as oxidation, diffusion, ion implantation, LPCVD, sputtering, etc., with a sophisticated micromachining processes. Some of the techniques are discussed below.

A) IC Fabrication

MEMS fabrication is developed from IC fabrication. As IC fabrication technology is having many advantages like low cost, high reliability and performance, these techniques and materials are implemented in MEMS fabrication[16]. This process is the usual technique which is used to manufacture typical integrated circuits. The IC fabrication consists in the application of the following steps, normally many times during the manufacturing. The process begins with a polished silicon – the substrate - wafer that undergoes these steps.

- **Thin film growth.** To build active and passive components, a thin film is needed to be deposited on the wafer. The type of film may includes epitaxial silicon, silicon dioxide (SiO₂), silicon nitride (Si₃N₄) polysilicon, a metal and others.
- **Doping.** To control the conductivity of the wafer at different locations, impurities like boron, phosphorous, etc. will be added by thermal deposition or ion implantation.
- **Lithography and etching.** Using masks designed to produce certain patterns on the wafer and using a photosensitive chemical called photo resist a pattern is generated and transferred to the wafer. The photolithography method is used to either add impurities or to etch the wafer in selected locations. The Etching is a process which is used to selectively remove unwanted regions of the thin film or substrate in order to delineate and shape the components. There are two modalities of etching: wet and dry etching.

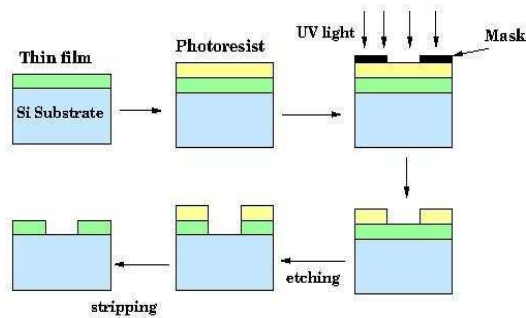


Figure 2: shows the main steps of the IC fabrication process.

The MEMS fabrication is still different from IC fabrication at some aspects. They are:

1. **Unconventional Materials** – The MEMS fabrication includes many variety of materials. Other than conventional materials used in IC fabrication, MEMS fabrication uses other materials also. MEMS fabrication can also be made from quartz, ceramics, and polyamide etc.

2. **Lack of Standard Processes** - IC fabrications have some certain standard processes, that can be used to implement all kinds of circuit functions. For example, by using the bulk micromachining method, pressure sensors and inkjet printing nozzles are fabricated, and by using the surface micromachining method, airbag accelerometers and micromirror projection arrays are fabricated. As of now there is no library of design rules available for MEMS

3. **Feature Size** - The Feature size of MEMS fabrication is usually larger than IC fabrication. Thus when IC fabrication feature size has been shrunk to 25nm, the smallest features of MEMS devices are still in 0.5um to 1um range. This leads to cheaper mask cost when compared to IC fabrication.

4. **Mechanical Properties** - MEMS fabrication considers the mechanical properties like residue stress, density, young's modulus etc. much more than IC fabrication. Because the need of MEMS fabrication is to make micromachines, we more care about their mechanical properties, specifically for material forming the structures. The properties include Young's modulus, yield strength, density, residual stress and stress gradients, and long term stability of these properties.

5. **Unique Unit Processes** - MEMS fabrication inherits many of unit processes from IC fabrication, however, it also has some specific requirements. MEMS fabrication utilizes the same photolithography, wet and dry etch, oxidation, diffusion, LPCVD, and sputter deposition same as IC fabrication. For improvising

mechanical performance like high sensitivity and better signal to noise ratio, MEMS fabrication needs much deeper etch, and much thicker deposition of materials (high aspect ratio) .

6. **Less Layers** – When compared to the IC fabrication, number of layers in MEMS fabrication is usually less. Some of the MEMS processes can be much simpler than the IC fabrication. This is due to the interconnection need in MEMS device is less than IC.

7. **Front/Back Side Processing** – Some of the MEMS devices need to be processed on both front side and back side while IC fabrication is focused on one side of the wafer. For example, the Pressure sensor needs etching on the backside to make cavity and membrane and doping on the front side to build the piezoresistors on the membrane, and the front-backside process alignment is required.

8. **MEMS Package Stress** – The Thermal and mechanical properties of package are the two important parameters to MEMS fabrication. The package stress can leads to the deflection and stress. MEMS structures and therefore change the device behavior while IC is less affected by mechanical stress. There are also differences in MEMS packaging, whether wafer- or die-level.

9. Several orders of magnitude difference in wafer volume

10. **Qualification of Process** After process and design lockdown, to transition to volume production, the process must be qualified by Statistical Quality Control & Statistical Process Control, (SQC/SPC) implementation.

To fabricate MEMS, we mention this before; along with the basic IC fabrication methods, it is needed to add a micromachining process involving the selective removal of silicon or the addition of other structural layers. Some of the widely used micromachining methods are discussed below.

MEMS fabrication techniques

1. **Bulk micromachining**
2. **Surface micromachining**
3. **Wafer Bonding**
4. **High aspect ratio MEMS fabrication techniques**
 - a. **Deep reactive ion etching of Silicon**
 - b. **Deep reactive ion etching of glass**
 - c. **LIGA**
 - d. **Hot embossing**

5. Low cost MEMS fabrication by Injection Molding

1. BULK MICROMACHINING

The oldest micromachining technology is bulk micromachining. This technique is used to selectively remove substrate to shape mechanical components. It can be accomplished using chemical (wet etch) or physical means (dry etch), with chemical means being far more widely used in the MEMS industry as it can provide high selectivity and high etch rate. [20] By simply changing the chemical composition of the etching liquid, the selectivity and etch rate can be altered.

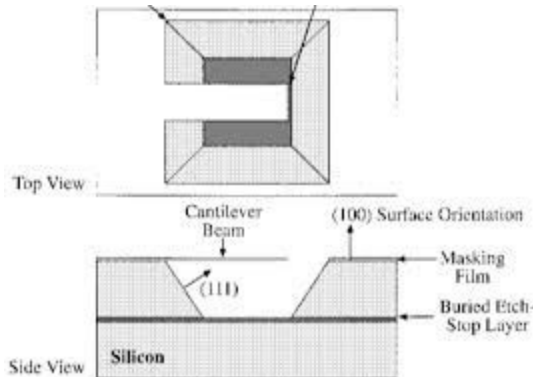


Fig 3: Bulk Micromachining Technique

Steps of MEMS Fabrication using Bulk Micromachining:

1. Circuit designing

The first step involves the circuit design and drawing of the circuit using software like PSpice or Proteus.

2. Simulation

The second step involves the simulation of the circuit and modeling using CAD (Computer-Aided Design) which is used to design the photolithographic mask which consists of the glass plate coated with chromium pattern.

3. Photolithography

Third step involves photolithography. In this step, a thin film of insulating material like Silicon Dioxide is coated on the silicon substrate, and over this, another layer called organic layer which is sensitive to UV rays is deposited using spin coating technique.

Then the photolithographic mask is placed in contact with the organic layer. The whole wafer is then subjected to ultraviolet radiation, which allows the pattern mask to be transferred to the organic layer. The uncovered oxide on the exposed photo resist is removed using HCl acid. The remaining photo resist is removed using hot Sulphuric acid and the resultant is an oxide pattern on the substrate, which is used as a mask.

4. Etching

After photolithography this step involves the removal of the unused silicon or etching. This step involves the removal of a bulk of the substrate using either 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 a particular direction (anisotropic etchant).

So, there are two types of wet etching in bulk micromachining: isotropic wet etching and anisotropic wet etching. In isotropic wet etching, the etch rate is not dependent on the crystallographic orientation of the substrate and the etching proceeds equally in all direction. The isotropic wet etching is almost always performed with vigorous stirring of the etchant solution. Commonly used etchants are HNA (Hydrofluoric acid, Nitric acid, and Acetic acid) and KOH(Potassium Hydroxide).

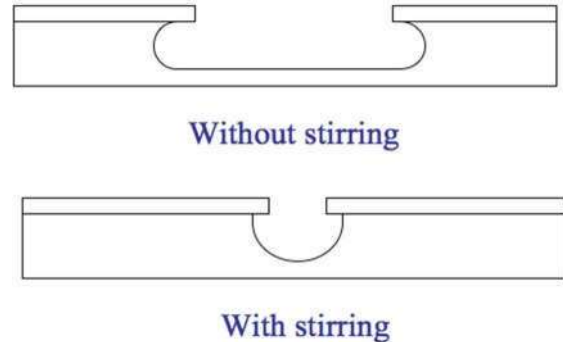


Figure 4: representation of etch profile, with and without stirring, using an isotropic wet chemical etchant

Franssila S, has described that, for all etching process it requires a masking material to be used, with preferably a high selectivity relative to the substrate material. For isotropic wet silicon etching commonly used masking material include silicon dioxide and

silicon nitride. The frequently used masking material is silicon nitride as it having lower etch rate.

The substrate material's dopant concentration is controlled by The etch rate of some isotropic wet etchant solution mixtures. For example: the commonly used mixture of $\text{HC}_2\text{H}_3\text{O}_2:\text{HNO}_3:\text{HF}$ in the ratio of 8:3:1 will etch highly doped silicon ($>5 \times 10^{18} \text{ atoms/cm}^3$) at a rate of 50 to 200 microns/hour. The etch rate selectivity with respect to dopant concentration is dependent on solution mixture.

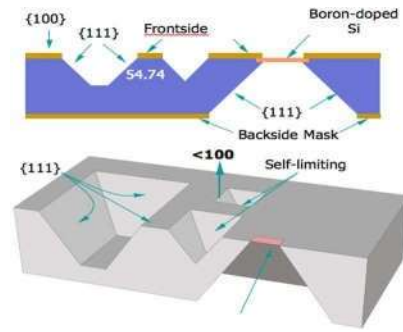
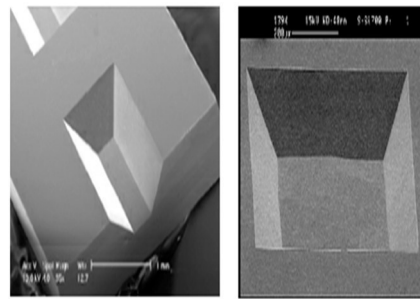


Figure 5: Illustration of shape of the etch profiles of a $\langle 100 \rangle$ oriented silicon substrate after immersion in an anisotropic wet etchant solution

Figure 5 below is an illustration of some of the shapes that are possible using anisotropic wet etching of $\langle 100 \rangle$ oriented silicon substrates including an inverted pyramidal and a flat bottomed trapezoidal etch pit. The shape of the etch pattern is primarily determined by the slower etching $\langle 111 \rangle$ planes. Figures 5a and 5b are SEM photographs of a silicon substrate after an anisotropic wet etching. Figure 5a shows a trapezoidal etch pit that has been subsequently diced across the etch pit and Figure 5b shows the backside of a thin membrane that could be used to make a pressure sensor. It is important to note that the etch profiles shown in the Figures are only for a $\langle 100 \rangle$ oriented silicon wafer; substrates with other crystallographic orientations will exhibit different shapes. Occasionally, substrates with other orientations are used in MEMS fabrication, but given the cost, lead times and availability, the vast majority of substrates used in bulk micromachining have $\langle 100 \rangle$ orientation



Etchant	Etch rate (110) $\mu\text{m}/\text{min}$	AR {100}/{111}	Etch Masks	Etch stop	Main characteristics
KOH	1,4	400	$\text{Si}_3\text{N}_4, \text{SiO}_2$	$B > 10^{20}/\text{cm}^3$	Fastest, greatest selectivity, makes vertical sidewalls
EDP	1,25	35	$\text{SiO}_2, \text{Si}_3\text{N}_4,$ Ta, Au, Cr, Ag, Cu	$B \sim 7 \times 10^{19}/\text{cm}^3$	Lots of masks, lowest Boron doping etch stop, low AR
TMAH	1	30	Si_3N_4	$B \sim 4 \times 10^{20}/\text{cm}^3$	Smooth surface, slow etch rate, low AR

Table 1. Basic properties of common anisotropic etchants

Figures 5a and 5b: SEMs of a $\langle 100 \rangle$ oriented silicon substrate after immersion in an anisotropic wet etchant.

5. Multiplayer wafer formation

In this step, to produce a multilayered wafer or a 3D structure, there is a necessity of joining two or more wafers. To form this structure, fusion bonding is used. The fusion bonding involves direct bonding between the layers or by using anodic bonding.

Figure 6. Wafer bonding

1. SURFACE MICROMACHINING

The surface micromachining is a popular technology which is used to construct the structural components for MEMS using thin film layers. The bulk micromachining process builds the components within a substrate whereas, surface micromachining builds on top of the substrate[32]. This involves a sequence of steps as shown below.

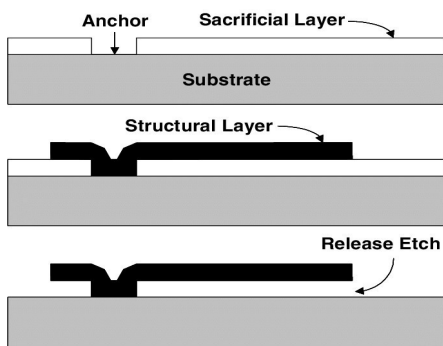


Fig 7: Surface micromachining process

Manufacturing of Cantilever Structure using Surface Micromachining

The first step involves the deposition of thin-film material to act as a temporary mechanical layer onto which the actual device layers are built; using a low-pressure chemical vapour deposition technique. This layer provides electrical isolation which is a sacrificial layer.

The second step involves the deposition and patterning of the thin-film device layer of material which is referred to as the structural layer; which can be a phosphor silicate glass, used to provide a structural base.

The third step involves etching of the layer using the dry etching technique. Dry etching technique can be reactive ion etching.

The fourth step involves the chemical deposition of phosphorus-doped polysilicon to form the structural layer.

The fifth step involves dry etching or removal of the temporary

layer to release the mechanical structure layer from the constraint of the underlying layer

The sixth step forms the required structure by removing the oxide layer and spacer layer.

An illustration of a surface micromachining process is shown in Figure 8. In the figure shown an oxide layer is deposited and patterned where this oxide layer is temporary and is commonly called as the sacrificial layer. Subsequently, a thin film layer of polysilicon [33] is deposited and patterned and this layer is the structural mechanical layer. Now the polysilicon layer is free to move as a cantilever by removing the sacrificial layer.

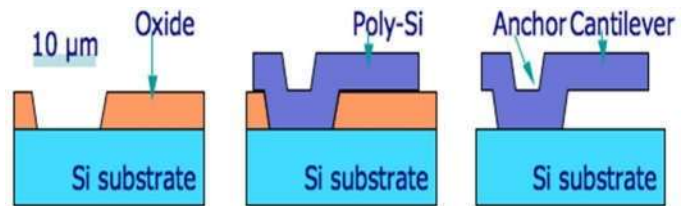


Figure 8: Illustration of a surface micromachining process.

The PSG sacrificial layer is most commonly used for surface micromachining and material combination. To release this device and to remove the PSG sacrificial layer, Hydrofluoric acid is used as an etchant. In the deployment of crash airbag, the analog devices integrated with MEMS accelerometer device is used for the fabrication by using the process called surface micro machining. The SEMs images of two surface micro machined polysilicon MEMS device are as shown in figure 9 and 10.

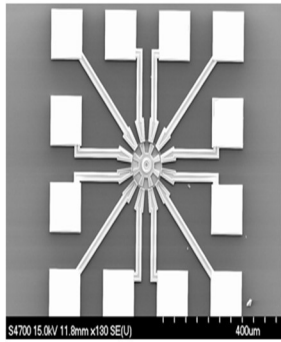


Figure 9: Polysilicon micromotor fabricated using a surface micromachining process.

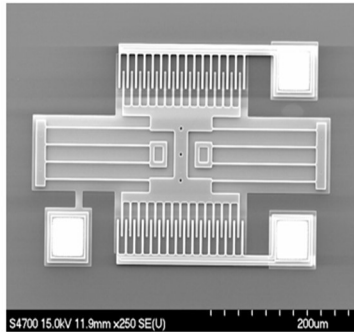


Figure 10: Polysilicon resonator structure fabricated using a surface micromachining process

The figure 11 illustrates polysilicon surface micromachining process. The complexity of the surface machining process is determined by the number of structural and sacrificial layers. [33] Two structural layers allow formation of free moving mechanical gears, springs, sliders, etc. The main advantage of surface micromachining over bulk micromachining is that many different devices can be realized using common fabrication process. By changing patterns on the photomask layouts different devices are being fabricated simultaneously on the same substrate. For that reason, the surface micromachining process is often referred to as an IC process that allows formation of multilayer structures usually with two to five polysilicon levels.

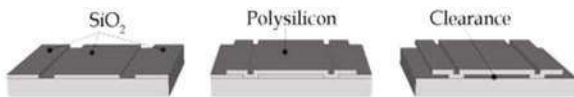


Figure 11. Polysilicon surface micromachining

Often, it is desirable to fabricate structures thicker than those achievable using polysilicon. An alternative micromachining process uses lithographic exposure of thick

photoresist, followed by electroplating to build on chip high aspect ratio 3D structures. In the LIGA(lithography, electroplating and molding) process synchrotron radiation is used as the exposure source that can achieve feature heights of the order of 500µm. cheaper alternatives use excimer lasers or UV mask aligners that achieve feature heights of the order of 200µm and 20µm, respectively. Parts are usually plated in nickel after removal of the resist as illustrated in Figure 12. The released metal layer can be used in various applications including optical MEMS devices.

The polysilicon surface micromachining process is as depicted in figure 11. By knowing the number of structural and sacrificial layers, the complexity of surface machining is determined [33]. By using the common fabrication process, many different devices can be realized. This is the main advantage of surface micromachining over bulk micromachining. The different devices are fabricated simultaneously on the same substrate, by changing the patterns on the photomask layouts. Thus surface micro machining method is similar to that of IC fabrication method.

For optical MEMS devices, and many more other applications the released metal layer can be used. The figure 12, illustrates the parts that are usually plated in nickel after removal of the resist.

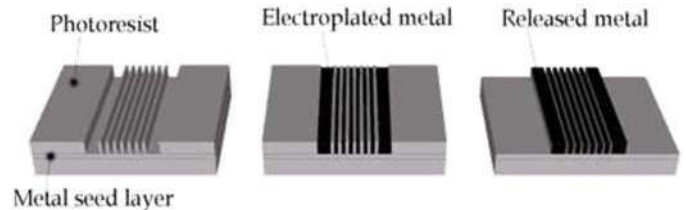


Figure 12. Metal micromachining

Based on BSOI i.e., bonded silicon on insulator standards, more reproducible properties than polysilicon are formed by using suspended single crystal Si structures, with lower stress. By thermal process, Si wafer is bonded to an oxidized Si substrate. Figure 13 shows, the bonded layer which is structured by deep reactive ion etching which has high etch rates and anisotropy to form very deep features with almost vertical sidewalls. And by removing the buried oxide, movable parts can be made.



Figure 13. Deep reactive ion etching (DRIE) of bonded silicon-on-insulator (BSOI)

The Si micro molding techniques allows DRIE such as HexSil process, to be developed. These Trenches are of a fraction of millimeter deep. To fill these trenches, a sacrificial oxide layer is deposited that is followed by the polysilicon structural layer. By releasing the polysilicon, deep suspended structures are made as shown in Figure 14.

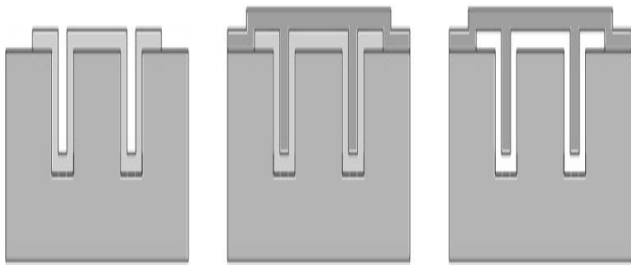


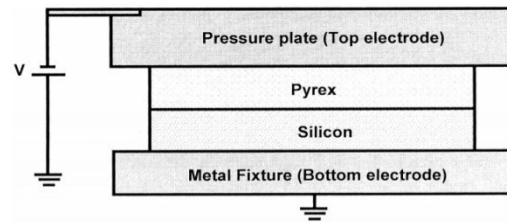
Figure 14. HexSil process

1. WAFER BONDING

The researcher Zheng Cui, has explained that, Wafer bonding is a technique of adhering two mirror-polished wafers of any materials at room temperature without applying any macroscopic gluing layer or external force. The bonding is achieved through Vander Waals force. When compared to metal bonding covalently or ironically bond solids, Wafer bonding achieved at room temperature is usually relatively weak. Thus heat treatment of bonded wafers is the best solution to strengthen the bonds across the interface. Thus Wafer bonding is a micromachining method that is analogous to welding in the macro scale world and involves the joining of two (or more) wafers together to create a multi-wafer stack.

K.N Bhat et al has said that, this technique play a key role in the present day silicon bulk micromachining for MEMS based sensors and actuators. Along with the wet or dry etching techniques, the wafer bonding technique can be used to realize (1) the membranes of thickness which will be differs from microns to several microns, that is applicable for pressure sensors, (2) complicated 3D structures for accelerometers and (3) multilayered device structures such as micro pump formicro

fluidicand biomedical applications, and (4) with the LIGA process that can competehigh aspect ratio structures



Basically there are 3 types of bonding: direct or fusion bonding; field-assisted

or anodic bonding; and bonding using an intermediate layer. In order to be the wafer bonding successful and free of voids all bonding methods require substrates that are very flat, smooth, and clean. The general process of the wafer bonding follows a three step sequence,andconsist of surface preparation, contacting and annealing,even though the process conditions used for all the three bonding techniques vary .With a high content of sodium,anodic bonding involves bonding a silicon wafer and a glass wafer. By applying a high voltage in the range 500 -1000 V and temperature maintained around 450°C,

the anodic bonding is carried out, and to attract Na^+ ions to the negative electrode where they are neutralized

Fig 15: Silicon –glass anodic bonding arrangement

A silicon wafer is bonded to a Pyrex 7740 wafer in anodic bonding, using an electric field and elevated temperature prior to bonding. The two wafers can be pre-processed and can be aligned during the bonding procedure.Pyrex 7740 has a high concentration of Na^+ ions, this is the mechanism by which anodic bonding works. The negative charge at glass surface is created by applying a positive voltage to the silicon wafer which drives the Na^+ ions from the Pyrex glass surface. The Anodic bonding is a widely used technique for MEMS packaging.

2. HIGH-ASPECT RATIO MEMS FABRICATION TECHNOLOGIES

a. Deep Reactive Ion Etching of Silicon

The Deep reactive ion etching or DRIE is a new fabrication technology that has been widely adopted by the MEMS. For silicon substrates this technology enables very high aspect ratio etches. The depth of the etch on the sidewalls can range from hundreds to thousands of microns into the silicon surface and etched holes are nearly vertical [28].

To alternately etch the silicon and deposit an etch resistant polymer layer on the sidewalls, the etchant of dry, high density plasma etch is used. On the sidewalls as well as on the bottom of the etch pit, the protective polymer layer is deposited but the anisotropy of an etch removes the polymer at the bottom of the etch pit. DRIE systems are single wafer tools. For DRIE etching Photoresist can be used as a masking layer [29]. The selectivity with photoresist is about 75 to 1 and oxide is about 150 to 1. Due to loading effects in the system, with larger exposed areas etching at a much faster rate compared to smaller exposed areas the process recipe depends on the amount of exposed silicon.

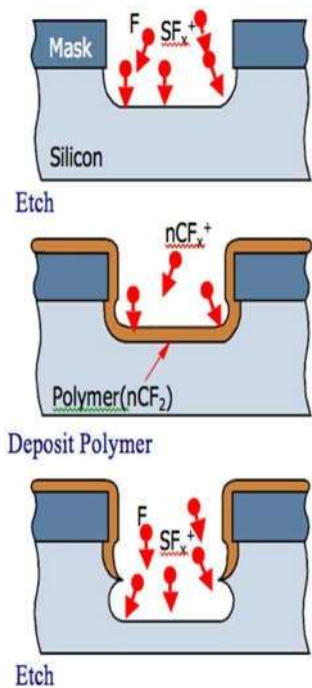


Figure 16: Illustration of how deep reactive ion etching works

Figure 17 is a SEM of a MEMS component fabricated using DRIE and wafer bonding. This device was made using an SOI wafer wherein a backside etch was performed through the handle wafer, stopping on the buried oxide layer, and a front side DRIE was performed on the SOI device layer. To release the microstructure to freely move, the buried oxide was removed. Figure 18 uses DRIE technology which is a cross section SEM of a silicon microstructure fabricated

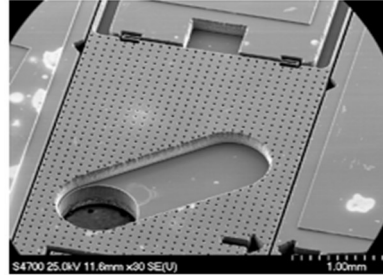


Figure 17: SEM of a MEMS device fabricated using two sided DRIE etching technology on an SOI wafer.

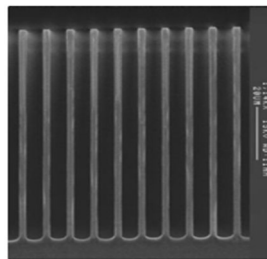


Figure 18: SEM of the cross section of a silicon wafer demonstrating high-aspect ratio and deep trenches that can be fabricated using DRIE technology.

a. Deep Reactive Ion Etching of Glass

This technology has been gaining in popularity in MEMS fabrication with high aspect ratios for Glass substrates which can also be etched deep into the material. The etching range is between 250 and 500 nm per minute for high aspect ratio glass. The metal or a polysilicon can be used as a mask depending on the depth of the photoresist.

b. LIGA

The LIGA is another high aspect ratio micromachining technology which is a German acronym for “Lithography Galvanoforming Ad forming.” On a single substrate this technique involves lithography, electroplating, and moulding

[27]. It requires the use of synchrotron generated x-ray radiation and it is primarily a non-silicon based technology.

c. Hot Embossing

By raising the temperature of the polymer just above its glass transition temperature, polymer is softened where hot embossing is essentially the stamping of a pattern on it [1]. The variety of ways including micromachining from silicon, LIGA, and machining using a CNC tool, the stamp is used to define the pattern in the polymer. For defining micro-channels and wells for fluidic devices, hot embossing technique is majorly used

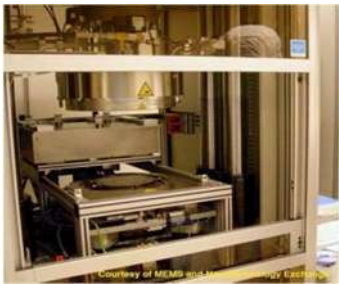


Fig 19:Photograph of a hot embossing platform during use.(Courtesy of the MNX at CNRI).

3. Low cost MEMS fabrication using injection molding

By using printing and injection moulding, the MEMS fabrication of large-area devices with low capital investment, without a vacuum process, and lower production costs is carried out. Henceforth for the fields where manufacturing cost was an criteria such as lighting, this technology is applied.

To produce integrated circuits, including vacuum processes, conventional commercial MEMS devices which uses fabrication techniques with semiconductor manufacturing systems. The production costs are high due to vacuum-based processes for the resins which is used to form patterns onto moving microstructures. The resins get harden immediately after mold injection thus it is difficult to form and thin MEMS structures such as springs and cantilevers.

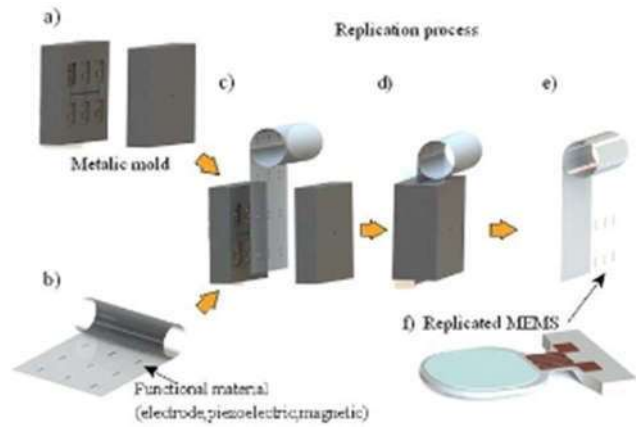


Figure 20: MEMS fabrication processes by printing and injection molding

The printed MEMS functional layers can be changed according to the desired purpose of the MEMS device — from acceleration sensors and gas sensors to power generation devices. This represents low cost MEMS fabrication in the sectors where costs are currently high. The AIST highlights is in light distribution control of LED lighting is one of the example. MEMS-based active light distribution control devices offers the new opportunities for this new MEMS fabrication technology, though, could produce low-cost large MEMS devices (larger than several mm across). By improving the arrangement of the optical system, the signal processing, and the control circuit it expands the range of the light distribution.

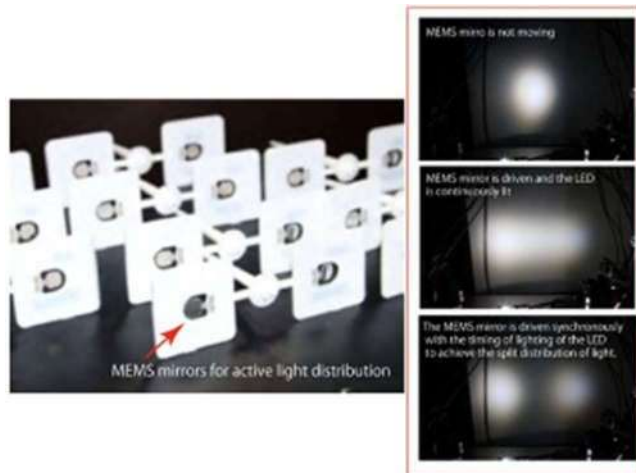


Figure 21: MEMS mirrors for active light distribution fabricated.

The left figure shows fabrication by using only printing and injection molding, and the right figure shows examples of the resulting light Distribution patterns.

APPLICATIONS OF MEMS

There are plenty of applications for MEMS[37]. MEMS combines the fields such as biology and microelectronics. And many new MEMS and Nanotechnology applications will come into existence, expanding beyond that which is currently identified or known.

MEMS technology finds wide applications in the below general domains

Automotive domain:The following are some of the devices where MEMS is widely applicable in this domain.

- Airbag Systems
- Vehicle Security Systems
- Inertial Brake Lights
- Headlight Levelling Rollover Detection
- Automatic Door Locks
- Active Suspension

Consumer domain:The following are some of the devices where MEMS is widely applicable in this domain

1. Appliances
2. Sports Training Devices
3. Computer Peripherals
4. Car and Personal Navigation Devices
5. Active Subwoofers

Industrial domain:The following are some of the devices where MEMS is widely applicable in this domain

1. Earthquake Detection and Gas Shutoff
2. Machine Health
3. Shock and Tilt Sensing

Military:The following are some of the devices where MEMS is widely applicable in this domain

1. Tanks
2. Planes
3. Equipment for Soldiers

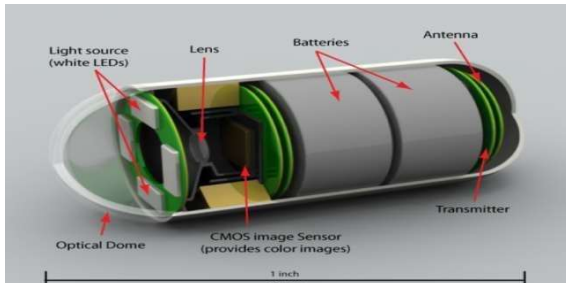


Fig 22: Pill Cam for Diagnostic applications

Biotechnology:The following are some of the devices where MEMS is widely applicable in this domain

1. Polymerase Chain Reaction (PCR) Microsystems for DNA amplification and identification
2. Micro machined Scanning Tunnelling Microscopes (STMs)
3. Biochips for detection of hazardous chemical and biological agents.
4. Microsystems for high-throughput drug screening and selection

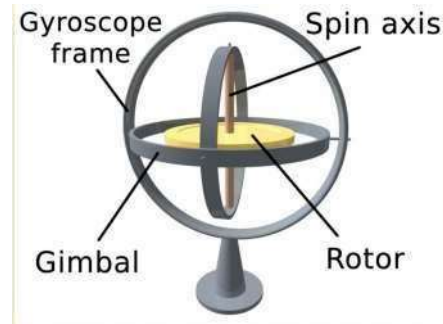


Fig 23: MEMS gyroscopes

MEMS devices:

Few examples of real MEMS products are,

1. Adaptive Optics for Ophthalmic Applications
2. Optical Cross Connects
3. Air Bag Accelerometers
4. Pressure Sensors
5. Mirror Arrays for Televisions and Displays
6. High Performance Steerable Micromirrors
7. RF MEMS Devices
8. Disposable Medical Devices
9. High Force, High Displacement Electrostatic Actuators
10. MEMS Devices for Secure Communications



Fig 24: MEMMS tire pressure sensor

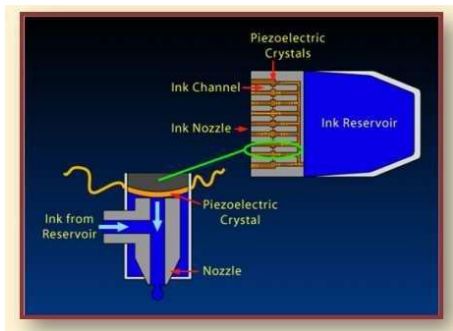


Fig 25: MEMS-based InkJet Printhead

CONCLUSION

The MEMS fabrication techniques are continuously developing till date, in this paper many different methods have been summarised. This survey and listing of all current methods may channelize the researchers to understand the development path of all fabrication techniques since from years ago on single paper. This endeavour may be believed to be a best source to understand the wide range of MEMS fabrication techniques. It also clearly differentiates the IC fabrication technique with MEMS fabrication. The work also involves the clear list of all applications of MEMS. We can conclude the current paper as a survey guide on all fabrication techniques.

REFERENCES:

- [1] Xian Yi et al, 2011 Fabrication of a MEMS micro-hotplate
- [2] Hongwei Qu, August 2015 CMOS MEMS Fabrication Technologies and Devices
- [3] Andreas C. Fischer et al 2015, Integrating MEMS and ICs
- [4] W. Fang et al 2013, CMOS MEMS: A key technology towards the "more than Moore" era
- [5] S. Madhava Reddy et al 2013 International journal of engineering sciences & Research technology
- [6] Ivanka Stanimirovic et al, Optical MEMS for Telecommunications: Some Reliability Issues
- [7] Bruce K. et al, 2007 Elsevier Low-Cost MEMS Technologies
- [8] Hongyi Yang et al, Focused Ion Beam micro machining and micro assembly.
- [9] Kenichi Takahata, Micro-Electro-Discharge Machining Technologies for MEMS.
- [10] Zheng Cui, wafer bonding
- [11] B. Lips et al, 2016, Three Step deep reactive ion etch for high density trench etching.
- [12] Ankashi Bhattacharya, 2007, Wafer bonding- A powerful tool for MEMS.
- [13] EETimes. MEMS Market to Top \$22 Billion by 2018. Available online: <http://www.eetimes.com> (accessed on 20 January 2016).
- [14] Baltes, H.; Paul, O.; Korvink, J.G.; Schneider, M.; Buhler, J.; Schneeberger, N.; Jaeggi, D.; Malcovati, P.; Hornung, M.; Hiberli, A.; et al. IC MEMS microtransducers. In Proceedings of the IEEE International Electron Devices Meeting, San Francisco, CA, USA, 8–11 December 1996; pp. 521–524
- [15] Baltes, H.; Brand, O.; Fedder, G.; Hierold, C.; Korvink, J.G.; Tabata, O. *CMOS-MEMS: Advanced Micro and Nanosystems*, 1st ed.; Wiley-VCH: Hoboken, NJ, USA, 2005.
- [16] International Technology Roadmap for Semiconductors (ITRS). Micro-Electro-Mechanical Systems (MEMS) Summary. Available online: <http://www.itrs2.net/> (accessed on 20 July 2015).
- [17] Vasudev, A. A.; Bhansali, S. 11- Microelectromechanical systems (MEMS) for in vivo applications. In *Inmann, A. A.; Hodgins, D. P. (Eds.) Sensor Systems for Medical Applications*. Woodhead Publishing, 2013, pp. 331–358.
- [18] Gad-el-Hak M 2002 *The MEMS Handbook* (Boca Raton: CRC PRESS)
- [19] Laconte J, Flandre D and Raskin J M 2006 Micromachined thin-film sensors for SOI-CMOS Co-Integration (Springer Ser. Chem. Phys.)
- [20] H. Xie, et al., *IEEE J. Microelectromech. Syst.*, vol. 11, no. 2, pp. 93–101, 2002.
- [21] Y.-C. Hsu, et al., *IEEE MEMS 2011*, Cancun, Mexico, 2011, pp. 589–592.
- [22] Ayon A A, Brauer R, Lin C C, Sawin H H and Schmidt M A 1999 *J. Electrochem. Soc.* 146 339–49
- [23] Jansen H V, De Boer M J, Unnikrishnan S, Louwse M C and Elwenspoek M C 2009 *J. Micromech. Microeng.*
- [24] Elwenspoek M and Jansen H V 2004 *Silicon Micromachining* (Cambridge: Cambridge University Press)
- [25] Ayon A A, Chen S, Lohner A, Spearing S M, Sawin H H and Schmidt M A 1998 *Proc. Material Research*
- [26] Meng L and Yan J 2015 *J. Micromech. Microeng.* 25 035024–32
- [27] Abgrall P, Lattes C, Conedera V, Dollat X, Colin S, Gue AM 2006 A novel fabrication method of flexible and monolithic 3D microfluidic structures using lamination of SU-8 films.
- [28] Becker H, Heim U 2000 Hot embossing as a method for the fabrication of polymer high aspect ratio structures. *Sens. Actuators* 83, 130–5
- [29] Conradie E H, Moore D F 2002 SU-8 thick photoresist processing as a functional material for MEMS applications *J. Micromech. Microeng.* 12, 368–74

- [30] Dotson N A, Kim P T, Mason A 2004 Low cost MEMS processing techniques. Proc. 2004 ASEE/NCS Spring conference.
- [31] Fuller S B, Wilhelm E J, Jacobson J M 2002 Ink-jet printed nanoparticle microelectromechanical systems
- [32] Franssila S 2004 Introduction to Microfabrication. Wiley & Sons UK
- [33] Hecke M 2003 Hot embossing – A flexible and successful replication technology for polymer MEMS. Proc. SPIE 5354,
- [34] Lee K, LaBianca N, Rishton S, Zohlgharnain S 1995 Micromachining applications for a high resolution ultra-thick photoresist. J. Vac. Sci. Technol. B 13, 3012–6
- [35] Tsai Y C, Jen H P, Lin K W, Hsieh Y Z 2006 Fabrication of microfluidic devices using dry film photoresist for microchip capillary electrophoresis. J. Chromatogr
- [36] Zhao Y, Cui T 2003 Fabrication of high-aspect-ratio polymer- based electrostatic comb drives using the hot embossing technique
- [37] J. Sniegowski, Multi-level polysilicon surface micromachining technology: Applications and issues
- [38] M. Mehregany and S. Roy, Introduction to MEMS, 2000, Microengineering M. Mehregany and S. Roy, Introduction