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Micromachining Techniques / Processes

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Abstract: ***A Micro–system is an intelligent miniaturized system comprising sensing, processing and actuating functions. A micro engineering refers to the technologies and practice of making three dimensional structure and devices with dimensioned in the order of micrometers. Micromachining is a basic technology used for the production of miniaturized parts and components. Micromachining resulted in the fabrication of a broad class of devices whose defining characteristics were micrometer scale feature size and electromechanical functionally, and these systems are collectively called as MEMs (Micro-Electro Mechanical Systems). Micro Electro Mechanical Systems, or MEMS, are micron-sized machines that can be used as mechanical, electrical, or chemical transducers. Many different fields such as the automotive and medical industries utilize MEMS because of four advantages: 1) easier to mass-produce, 2) lower cost of production, 3) easier to make part alterations, and 4) higher reliability compared to large-scale machines. MEMS are generally made of Polycrystalline Silicon, which is the same material used to make integrated circuits (IC). To manufacture MEMS devices, a process called photolithography is used. The general steps of the two-mask photolithography process are discussed. We can produce many type of MEMS devices using photolithography. One of the most notable applications of MEMS devices is the accelerometer (crash sensor) of the airbag deployment system in modern automobiles. MEMS crash sensor will replace the less capable large-scale device for a fraction of the cost. MEMS development has just begun and researchers as well as engineers are working hard to create more and better MEMS devices to serve us in the future.***

Keywords: Fabrication techniques, miniaturization, integrated micro instrument, sensors and actuator

1. Introduction

1.1 History

Electro-mechanical systems are tiny electromechanical devices made by some of the same methods as integrated circuits. The results are some of the smallest machines ever made, capable being built on a silicon wafer alongside the circuits that control them. Most MEMs devices are still experimental, but they are already being used in cars to deploy airbags and actuate antilock brakes, in integrated capital switches to handle internet traffic, and in many other areas.

MEMs were first proposed in the 1980s. Engineers and scientists wanted to use integrated circuits fabrication techniques to make tiny mechanical systems, which could, if necessary, be connected to electronic circuits on the same chips. One of the first commercial application of MEMs was the tiny nozzle assembly used in the catridges of inkjet printers.

In 1982, automotive airbags systems were introduced using MEMs sensors to detect a crash. The analog devices corporation elaborated this idea, producing an "accelerometer" for airbags systems in 1991, where the mechanical and electronic portions were integrated on the chip. The accelerometer chip detects the sudden increase or decrease in speed that occurs during a crash. The same company later introduced a gyroscope-on-a-chip, capable of working with an automobiles global positioning system to create more accurate maps and directions for drivers.

1.2 What is Micromachining (MEMS) Technology?

Micro-Electro-Mechanical Systems (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through the utilization of microfabrication technology. Using the fabrication techniques and materials of microelectronics as MEMS processes construct both mechanical and electrical components. Mechanical components in MEMS, like transistors in microelectronics, have dimensions that are measured in microns and numbers measured from a few to millions. It can be difficult for one to imagine the size of a MEMS device. The general size of MEMS is on the order of microns (10^{-6} meter) as shown by the illustration of the MEMS gear**.** The main characteristic of MEMS is their small size. Due to their size, MEMS cannot be seen with the unaided eye. An optical microscope is usually required for one to be able to see them.

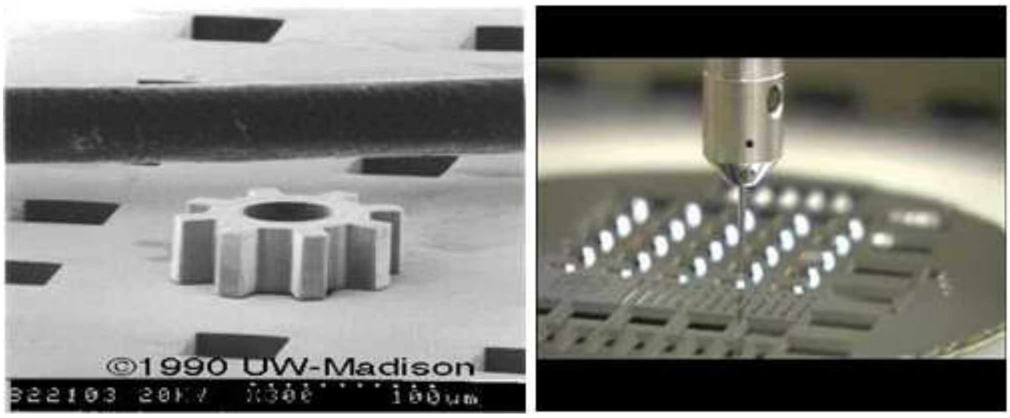


Figure 1: A MEMS Gear and drilling operation in comparison to a humanhair
(Source: University of Wisconsin at Madison MEMS research laboratory, 1990)

MEMS is not about any single application or device, nor is it defined by a single fabrication process or limited to a few materials. More than any thing else MEMS is a fabrication approach that conveys the advantages of **miniaturization, multiple components and microelectronics** to the design and construction of **integrated electromechanical systems.** While the electronics are fabricated using integrated circuit (IC) process sequences (e.g., CMOS, Bipolar, or BICMOS processes), the micro mechanical components are fabricated using compatible "micro machining" processes that selectively etch away parts of the silicon wafer or add new structural layers to form the mechanical and electromechanical devices. MEMS promises to revolutionize nearly every product category by bringing together silicon-based microelectronics with micro machining technology, thereby, making possible the realization of complete **systems-on-a-chip**. MEMS is truly an enabling technology allowing the development of smart products by augmenting the computational ability of microelectronics with the perception and control capabilities of microsensors and microactuators. MEMS is also an extremely diverse and fertile technology, both in the applications as well as in how the devices are designed and manufactured. MEMS technology makes possible the integration of microelectronics with active perception and control functions, thereby, greatly expanding the design and application.

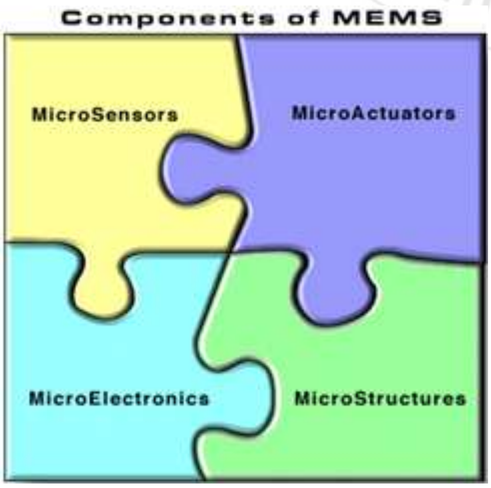


Figure 2: Components of MEMS

Microelectronic integrated circuits (ICs) can be thought of as the "brains" of systems and MEMS augments this decision-making capability with "eyes" and "arms", to allow Microsystems to sense and control the environment. In its most basic form, the sensors gather information from the environment through measuring mechanical, thermal, biological, chemical, optical, and magnetic phenomena; the electronics process the information derived from the sensors and through some decision making capability direct the actuators to respond by moving, positioning, regulating, pumping, and filtering, thereby, controlling the environment for some desired outcome or purpose. 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. Common examples of MEMS devices are the crash sensors of the airbag deployment system on modern automobiles and the pressure sensors in medical applications.

2. Materials

Although micromachining techniques are not limited by choice of materials, historically micromachining has developed around silicon and associated materials because the technology is well established in the area of VLSI (very large scale integration) and processes involved are well known. The most fundamental material is crystalline silicon because it forms the substrate or the foundation for most micromachined devices.

2.1 Silicon Wafer

In integrated-circuit (IC) fabrication silicon is used mainly as a substrate, in micromachining it usually is the structural material of the mechanical devices because it is very strong, has a similar modulus of elasticity to that of steel, and lacks mechanical hysteresis, and other environmental factors. Silicon wafers are etched and bonded to other silicon devices to form composite silicon structure. In most applications, one uses standard wafers used by IC industry because they tend to be lowest in cost. The variation in the wafer thickness specifications can sometimes put limitations on the accuracy with which bulk-micromachined parts can be made.

Silicon crystals can be formed by simple repetition of the basic unit cell, which consists of the atoms arranged in the zincblende structure[1]. Each of the faces of the unit cell can be described by a vector such as < 100 > , < 110 > or < 111 >.

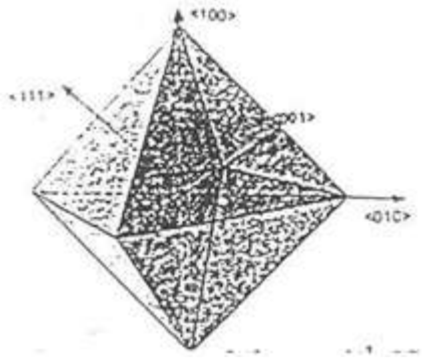


Figure 3: Spatial position of the crystal octahedron

The basic spatial structure that describes the < 111 > planes in monocrystalline silicon is the octahedron as shown in **fig.3.**. For < 100 > oriented silicon, this octahedron structure is oriented with the length axis-oriented perpendicular to the wafer surface . For < 111 > oriented silicon , the structure is rotated over 54.7° such that one of the < 111 > facets is oriented in the wafer plane. The < 100 > wafers have traditionally been used for the bipolar circuit process, while < 100 > wafers are mostly used in metal oxide semiconductor(MOS) processes because of superior oxidation properties. Crystal structure helps in making grooves and cavities in MEMS devices.

2.2. Thin-Film Materials

Thin films play the role of both a structural material and a fabrication aid. For example, in surface micromachines, micromechanical structures are formed from polysilicon thin films, whereas silicon oxide thin films are used as sacrificial layers and are removed in the final structure[3]. There are atleast three types of thin films that are central to silicon based micromachining or microfabrication. They are silicon dioxide, silicon nitride, and polysilicon thin films. Each type of film is fabricated in different ways and the growth mechanism affects the stress in thin films.

Silicon dioxide is perhaps the most widely used thin-film material in MEMS. It can serve as an electrical and thermal insulator, as a sacrificial layer, or as a stress compensator.

Thermal oxides are the easiest thin films to grow in a laboratory. Silicon substrate is thermally converted to silicon dioxide by reacting with dry oxygen or wet steam . A disadvantage of thermal oxidation is the high temperatures (900°C-1050°C) needed to achieve films of the required thickness in a reasonable time period.

Typical masking layers on silicon are thermally grown oxide and low-stress silicon nitride thin films. Silicon dioxide films generally etch faster than silicon nitride films. This fact would suggest the use of silicon nitride films for masking material . However , silicon dioxide films have two distinct advantages: it is commonly available from thermal oxidation furnaces and they can be easily dissolve away from the wafer after anisotropic etch .

3. Manufacturing Process

1) Photolithography (Surface Micro machining)
2) LIGA (Lithographie, Galvanoformung, Abformung)
3) Bulk Micro machining
4) EDM (Electrical Discharge Machining)
5) Surface Micromachining

1) Photolithography (surface Micro machining):
The most frequently used manufacturing technique is called surface micro machining. The term micro machining is a little deceptive since no machining is actually done.

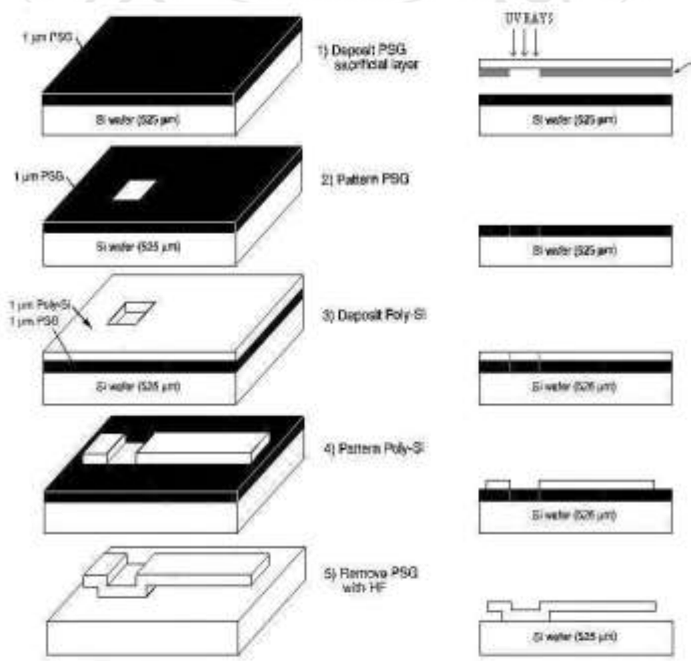


Figure 4: Schematic of process steps to fabricate a cantilever beam using a two-mask Photolithography process

The term micro machining is applied to a broad array of techniques that all utilize photo chemical etching to produce parts. This process is also referred to as **photolithography.**

This process is used to mass-produce MEMS devices such as micromotors and microvalves. The term photolithography is derived from Greek words: *phos* (light), *lithos* (stone) and *graphein* (to write). The process involves utilizing ultraviolet (UV) light to "write" images onto the surface of a silicon wafer followed by plasma etching* to create the MEMS devices. The general steps of the two-mask photolithography process are discussed bellow. This process is the basis of more complex photolithography processes and is often used to produce simple MEMS structures such as cantilever beams.

There are five steps in the two-mask-photolithography process as shown in figure3:

- Depositing a sacrificial layer onto a Si wafer.
- Exposing the sacrificial layer to a UV light and etching it with plasma gas.
- Depositing a layer of Poly-Si onto the sacrificial layer.
- Exposing the Poly-Si layer to a UV light and etching it with plasma gas.
- Etching the sacrificial layer with Hydrofluoric acid.

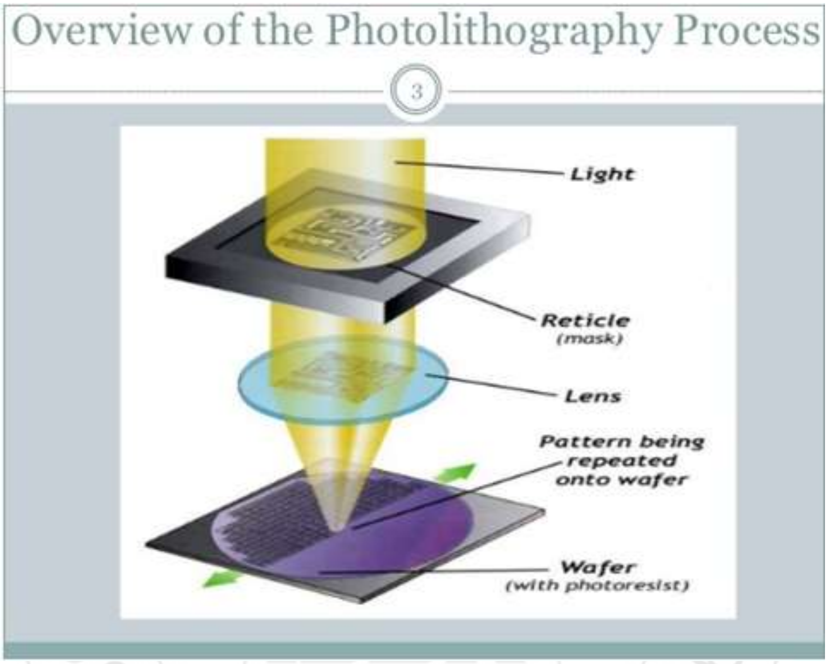


Figure 5: Photolithograpy process

Elaboration of the two-mask photolithography process is as follow:

First, a thin, one-micron thick sacrificial layer of Phosphosilicate glass (PSG) is deposited onto a silicon wafer that is 525 microns thick. Before the PSG layer is exposed to UV light, a mask with a rectangular hole is used to cover some of the PSG layer. The rectangular part of the PSG layer that was not covered is then exposed to UV light. Then, a plasma etch is performed to remove the UV exposed PSG layer.

At this point, we have created a hole for the Poly-Si cantilever beam from the PSG. The third step of the two-mask photolithography process is to deposit a thin, one-micron thick layer of Poly-Si onto the remaining PSG layer. A second rectangular mask is used to cover some parts of the Poly-Si layer before exposing the Poly-Si layer to UV light. A second plasma etch is then done to remove the UV exposed Poly-Si layer.

The last step is to "release" the Poly-Si cantilever beam from the PSG layer by etching the PSG layer with Hydrofluoric acid (HF) for a given amount of time. Note that adding more “depositing-exposing-etching” steps to the two-mask photolithography process can make more complicated MEMS structures such as the micro- servomotor**.**

Advantages of Photolithograpy:

1) It is very fast.
2) It is cheap

Disadvantages of Photolithograpy :

1) It cannot produced very high quality prints.

2) Liga (Lithographie, Galvanoformung, Abformung) :

The acronym LIGA comes from the German name for the process (**Li**thographie, **G**alvanoformung, **A**bformung). LIGA uses lithography, electroplating, and moulding processes to produce microstructures. It is capable of creating very finely defined microstructures of up to 1000µm high.

In the process as originally developed, a special kind of photolithography using X-rays (X-ray lithography) is used to produce patterns in very thick layers of photoresist. The X-rays from a synchrotron source are shone through a special mask onto a thick photoresist layer (sensitive to X-rays), which covers a conductive substrate (a). This resist is then developed (b).

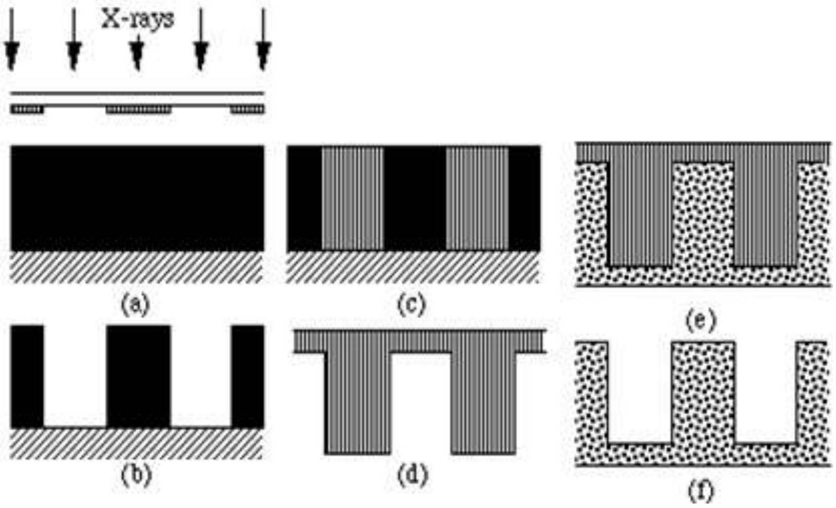


Figure 6: Schematic of process steps involved in LIGA.

The pattern formed is then electroplated with metal (c). The metal structures produced can be the final product; however it is common to produce a metal mould (d). This mould can then be filled with a suitable material, such as a plastic (e), to produce the finished product in that material (f). These moulds also allow the use of materials other than silicon, such as nickel, titanium, and gold.

Because of the patterning technique employed by LIGA, structures with a wide range of materials can be fabricated. These structures can have horizontal tolerances of about 0.3 microns and vertical dimensions from microns to centimeters. One disadvantage of the Liga process is the cost of X-ray radiation equipment used to develop the photopolymer. In addition to costing millions of dollars, the radiation emissions are tightly controlled by federal regulation. This limits the use of this process to only a handful of institutions in the United States.

Advantages of LIGA:
1)Allows material other than Si to be used.
2)Better precision and low surface roughness.
3)Mass production of parts is possible.

Disadvantages of LIGA :
1)Synchroton radiation source is not widely available.
2)Resuts may vary depending on the deposition method used.

3) Bulk Silicon Micromachining

Bulk micromachining refers to selective bulk removal of the substrate. Bulk micromachining involves etching of the silicon wafers, either isotropically or anisotropically, to form mechanical structures. Furthermore, bulk-etched structures formed from multiple silicon wafers can be bonded using several bonding techniques [5]. In a typical silicon bulk etch; a masking layer that does not etch in the silicon etchant is first deposited over the silicon wafer. Although one would like to use photoresist as the masking material, it unfortunately is attracted and etched easily by most silicon etched easily by most silicon etchants. Instead, photoresist-based lithography is used to define patterns in a suitable mask material such as silicon dioxide or silicon nitride.

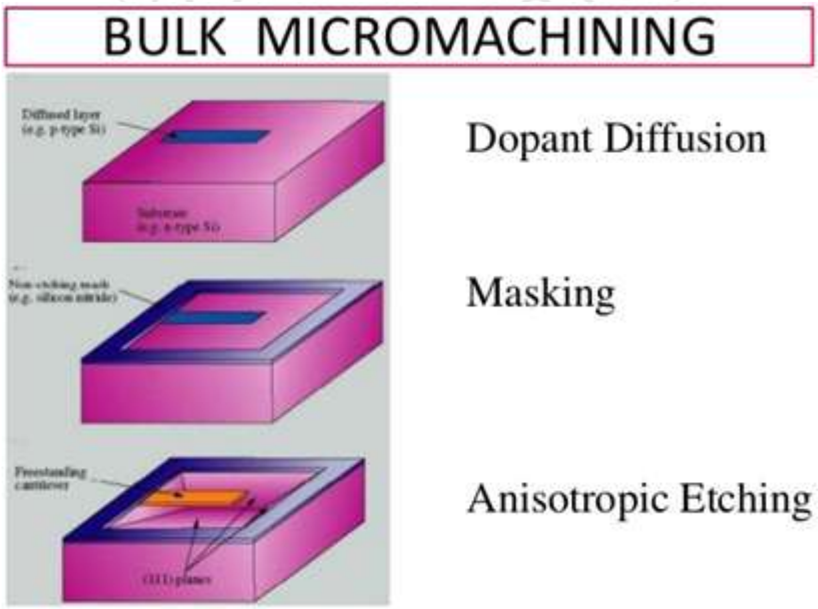
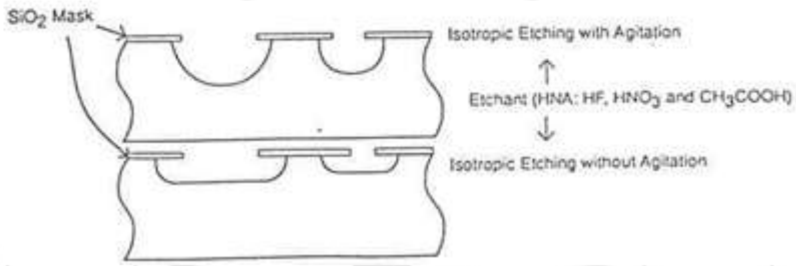


Figure 7: bulk micro-machining

Most silicon etchants are used at an elevated temperature with a controlled concentration of the etchant in a solution with water as the main solvent . The etching temperature is typically kept below the etchant boiling point to avoid rapid loss by evaporation. The masked silicon wafer is placed in such a temperature-controlled etching chamber and the exposed silicon is put in contact with the electrolyte in which charge transfer takes place. The surface silicon atoms undergo chemical reactions that results in silicon removal from the solid to the liquid state.

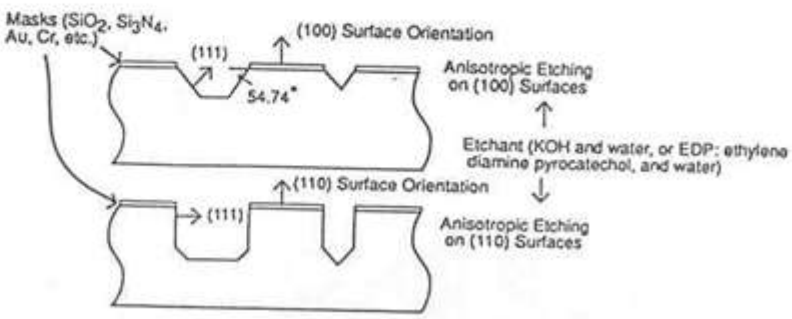
3.1. Isotropic etching

Several chemical etchants etch silicon without regard to the crystalline orientation. An important family of etchants is the mixture of hydrofluoric acid, nitric acid, and acetic acid mixed with water. This is called the HNA mixture. The nitric acid oxidizes silicon surface, which is subsequently etched by the hydrofluoric acid with acetic acid used as a chemical buffer. Different etching rates and etched surfaces are obtained, depending on the concentrations of etch behavior in a phase diagram representation . It can be seen that very high etch rates are possible in the polishing regime. One can dissolve an entire silicon wafer (550 µm thick) in HNA in approximately 20 min. However, these high etch rates are accompanied by high masking-layer etch rate. Even silicon nitride, which is usually chemically inert, is etched very fast and cannot be used reliably. The chemical reactions are also highly exothermic, resulting in higher reaction zone temperatures and, ultimately, extreme etch non-uniformity. Slower-etch-rate mixtures result in more uniform and controllable etching and are used regularly to etch silicon and polysilicon films in both micromachining and the integrated-circuit industry. Placing the silicon wafer inside the etchant removes silicon equally in all directions, as shown in **fig.**



3.2. Anisotropic etching

Anisotropic etching originates from the wide variation in silicon etching rates as a function of the exposed crystal planes[2]. Etchants used in anisotropic etching are KOH and EDP. The depth of etch at a particular angle indicates the etch rate of the crystal associated with the crystal angle. It is seen that the <111> direction has the lower etching rate and <100> has the highest etch rate. One reason for the etch-rate difference is believed to the surface atomic density variations as a function of the crystal plane direction. To utilize anisotropic etching reproducibly, one has to align the wafer flat to the exposure mask reproducibly. Sometimes special jigs during contact lithography are used to align the mask to the wafer flat so that etching occurs with respect to a certain direction. Most commonly, anisotropic etching is done on <100> or <110> wafers with <111> planes as etch stops. In the case of <100> wafers, the <111> crystal planes are oriented at a 54.74° angle to the wafer surface and produce a wall with that angle. Anisotropic etching on wafers with <110> orientation can produce vertical walls as shown in.



Two etch ratios are important in anisotropic etching. First is the anisotropy ratio, which is the ratio between the etch rate of the crystal plane to be etched (<100> or <110>) and the etch stop plane (<111>). The second is the ratio of the silicon etch rate to the mask-etch rate, called the mask-etch-rate ratio. As the etching rates for mask materials and substrate materials are Arrhenius functions of temperature with different activation energies, the mask-etch-rate ratio and the anisotropy ratio are also functions of temperature. For a given desired etch depth and mask-etch-rate ratio, one can calculate the required mask thickness.

3.3 Plasma etching

In a typical plasma etching, the reactive gas is mixed with a dilutant gas and exposed to high-energy radio frequency (rf) electric and magnetic fields as shown in the **fig**

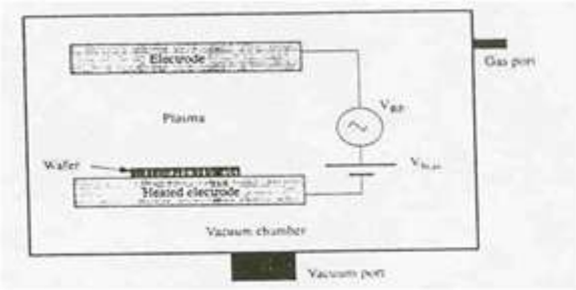


Figure 8: Components of a typical plasma system

These fields ionize the gas molecules, creating electrons that further ionize the gas and result in a stable phase of ions and electrons. For plasma etching, the reactive ions hit the target surface, diffuse on the surface, react with the surface atoms, to form gases that diffuse away into the plasma. If the ions are very energetic, pure physical etching can occur by ion-surface momentum transfer during impact. If the ions are not very energetic, chemical reactions of charged species take place, which are controlled by the plasma pressure, temperature, and power. A few of the different kinds of etch profiles obtainable from plasma etching.

Advantages of Bulk Micromachining (over Surface Micromachining)

1) High-aspect ratio microstructures can be made using bulk micromachining.
2) High rigid qualitative monocrystalline structures can be etched.
3) Pre-stress, creep and stress relaxation are less pronounced and better fatigue resistance is obtained.
4) Bulk etching techniques are well suited for application areas where high demands are put on mechanical and time dependent material properties.
5) Possibility to fabricate microstructures, built from rather thick material layers, cavities and trenches well over a few micrometers in depth.
6) Besides, bulk processed silicon structures can be used as a mould to grow other construction materials.

Disadvantages of Bulk Micromachining:

1) Relatively large silicon is consumed
2) Lack of compatibility with CMOS.

4) EDM (Electrical discharge machining)

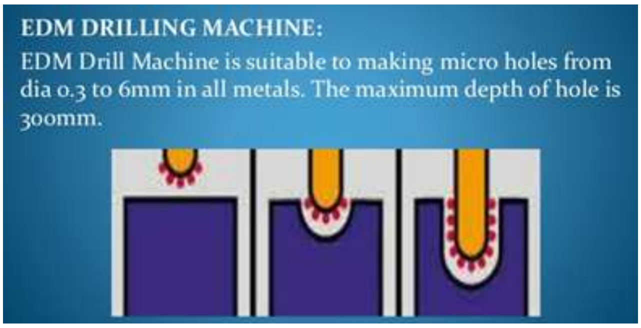


Figure 9: EDM

It also known as spark machining, spark eroding, burning, die sinking, wire burning, or wire erosion. It is manufacturing process whereby a desired shape is obtained by using electrical discharges (sparks). Material is removed from the workpiece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One electrode is known as the tool-electrode , or simply the tool or electrode , while the other called as the workpiece-electrode , or workpiece. The process depends upon the tool and workpiece not making actual contact. When the voltage between the two electrodes is increased, the intensity of the electric field in the volume between the electrodes becomes greater than strength of the dielectric, which breaks down, allowing current to flow between the two electrodes. As the result, material is removed from electrodes.

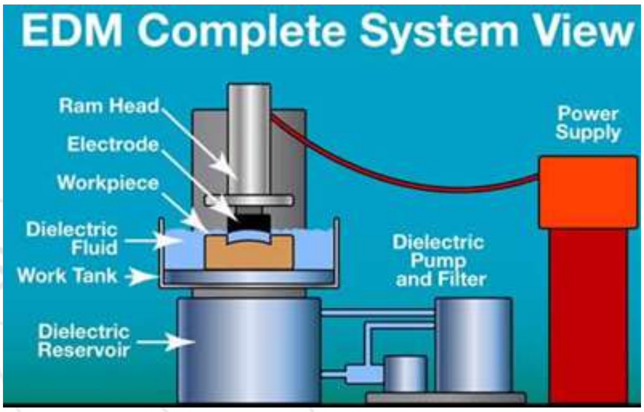


Figure 10: System view of EDM

Advantages of EDM

1) Complex shapes that would otherwise be difficult to produce with conventional cutting tools.
2) Extremely hard material to very close tolerances.
3) Very small work pieces where conventional cutting tools may damage the part from excess cutting pressure.
4) Very fine holes can be attained.
5) Tapered holes may be produced.

Disadvantages of EDM

1) The slow rate of material removal.
2) Power consumption is high.
3) Excessive tool wear occurs during machining.

5) Surface Micromachining:

A sacrificial layer material is deposited first on a silicon wafer by low-pressure chemical vapor deposition (LPCVD) [8] and coated with a layer such as silicon nitride. Lithography is used to define areas where the sacrificial etch is removed selectively. A conformal thin film of the structural material is deposited over the entire wafer. Then the entire wafer is etched in an etch that selectively etches the sacrificial film to that of the structure has to be very high to maintain controllable structural layer thickness.

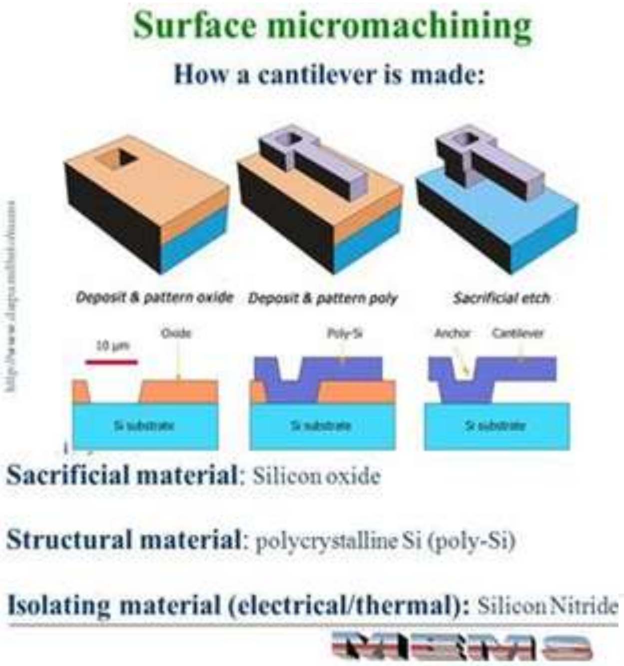


Figure 11: Surface micromachining

Furthermore, the interfacial stresses between the sacrificial layer and the structural layer, as well as the internal stresses of the structural layer, have to be very low to avoid curling of the structural material after the release step. Surface micromachining is used for fabrication of cantilever-type accelerometer as described later.

Advantages

1) In surface micromachining, structural shape is defined by reactive ion etching (RIE), which allows fabricating arbitrary patterns.
2) Surface finish of surface micromachining structures is better than other methods.

Disadvantages

1) Micromachining 2 µm-thick film takes several hours or more.
2) It is very difficult to grow and control the properties of thick polysilicon films such as residual stress; stress gradient and young's modulus. So there have been many attempts to develop a surface micromachining like process using single crystal silicon.

4. Advantage of Micromachining

There are four main advantages of using MEMS rather than ordinary large scale machinery. The first advantage **is the ease of production**. Borrowed from the IC industry, today's VLSI (Very Large Scale Integration) technology allows MEMS to be produced in large quantities (up to 100,000 MEMS devices per Poly-Si wafer). It is obvious that no macro-machinery production rate can even come close to this number.

The second advantage of MEMS **is that they can be mass-produced and, thus, are inexpensive to make.** A single MEMS device only costs a small fraction of a cent to produce.

The third advantage of MEMS over macro-machinery **is the ease of parts alteration.** To alter the production of a macro-machinery part, it is sometimes necessary to revise a whole production line, which involves a plant-wide shut down that can cause major loss in production time and money. A new set of MEMS can be created by making minor alterations in the manufacturing process (i.e. change of masks, change of etch time).**Lastly, MEMS devices are known to have higher reliability than their macro scale counterparts.**

5. Limitations and Disadvantages

Due to their size, it is physically impossible for MEMS to transfer any significant power. In addition, because MEMS are made from Poly-Si (a brittle material) they cannot be loaded with large forces. This is because brittle materials can be fractured easily under high stress. Many MEMS researchers are working hard to improve MEMS's material strength and ability to transfer mechanical power. Nevertheless, despite these limitations, MEMS still have countless numbers of applications in the real world as discussed in the next section.

6. Applications

6.1 Automotive Application

In automobiles that are made today there are 20 to 30 odd MEMS devices. These are mostly sensors like accelerometers, pressure sensors, and gyroscopes. The accelerometers are used to sense a collision and produce the signal that deploys air bags in cars. An advantage of these devices is the fact that they can be arranged on a single chip to detect side or front impacts and deploy the corresponding air bags. These devices come complete with microscopic springs, masses, and cantilevers. Another big use is in the production of Manifold Absolute Pressure sensors, which are referred to as MAP sensors. These sensors are used to determine the concentration of oxygen going into the engine and calibrate the fuel air mixture to insure engine performance under a variety of environmental conditions. Map sensors also produce higher fuel efficiency.

6.1.1. Airbag deployment system:

One can find many MEMS applications in the automotive, biomedical, data storage, micro-optics, robotics and fluid control fields. **But one of the most notable MEMS application is the accelerometer (a device used to measure acceleration) found in the airbag deployment system of many modern automobiles.** These accelerometers are used as crash sensors in an airbag deployment system. We will now discuss how the traditional airbag deployment system works.

A traditional airbag deployment system includes macro mechanical crash sensors which detect a crash pulse, a microprocessor which processes signals from the crash sensors and an **airbag deployment mechanism which physically deploys the airbag in an event of a collision.** The traditional airbag deployment system uses a "ball-on-cone type" macro mechanical device as the crash sensor. When the deceleration of a vehicle exceeds a certain limit (signal of hard braking or collision), the decelerating forces would pull the ball to a position which signals the system to deploy the airbag The inflated airbag will then act as a cushion between the occupants and the dashboard thus lessens the impact force imparted to the occupants by the crash. Airbags are designed to protect the occupants in automobile accidents against severe injuries. The airbag deployment system has been proven an effective supplemental restraint system (SRS) when used concurrently with safety seat belts.

We will now discuss the advantages of using MEMS as crash sensors in the airbag deployment system rather than macro devices:

Advantages

MEMS are used for crash sensing in newer airbag deployment systems because the traditional macro mechanical devices are not capable of meeting new standards set by the government and the auto industry. These new standards include the need of multi-directional crash sensing which cannot be achieved by the traditional crash sensors. In addition, traditional crash sensors are more expensive to make and less reliable compared to the MEMS crash sensors. **We will now discuss the details of the MEMS crash-sensing device.**

6.1.2. Two-chip accelerometer system:

The two-chip accelerometer system is used as the crash sensor in the airbag deployment system. It consists of three layers of Poly-Si as shown in **figure 5.**Each layer has a particular function. The first fixed layer is used to run a self-diagnostic test every time the device is powered up. The third fixed layer is a reference electrode. The second layer is a seismic mass, which is capable of moving up and down between the first and third layer when subjected to acceleration (in the direction in or out of the paper).

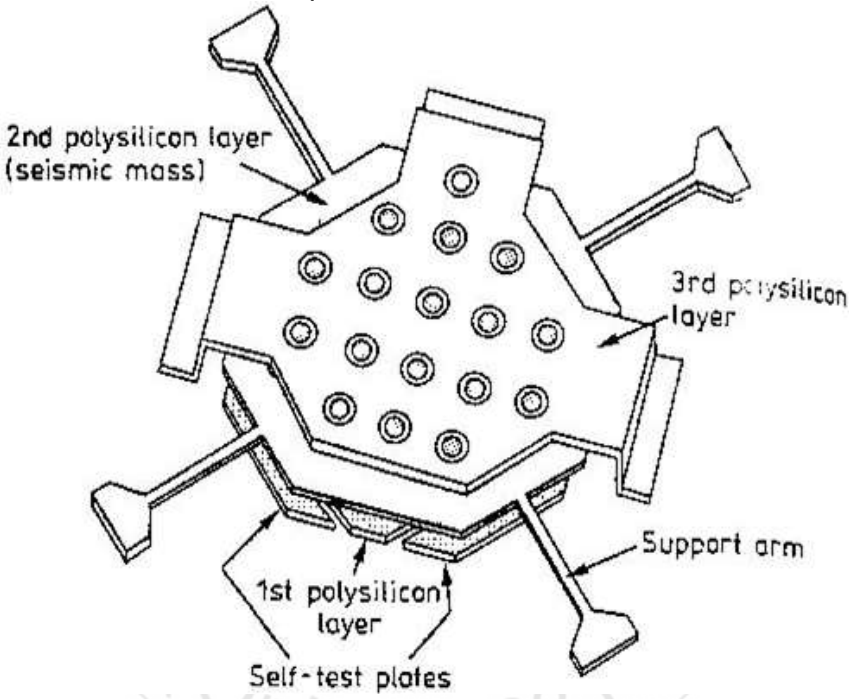


Figure 12: Schematic representation of the three-layer micro mechanical capacitive structure in an accelerometer system

The sandwich of Poly-Si layers (the crash sensor) is connected to a microprocessor which is connected to the deploying mechanism of the airbag (see figure 6). At zero acceleration, a fixed capacitance (an electrical property) is measured between the second and third Poly-Si layer. The system is said to be "at rest" in this state. In an event of a collision, a great deceleration force would be transmitted to the accelerometer. This force would move the seismic mass (the second layer) with respect to the fixed third layer. The change in spacing between these two layers will cause a change in the capacitance. This change in capacitance is analyzed by the microprocessor attached to the crash sensing unit. If the change is severe enough (meaning a real collision is in progress), the microprocessor will send a signal to deploy the airbag.

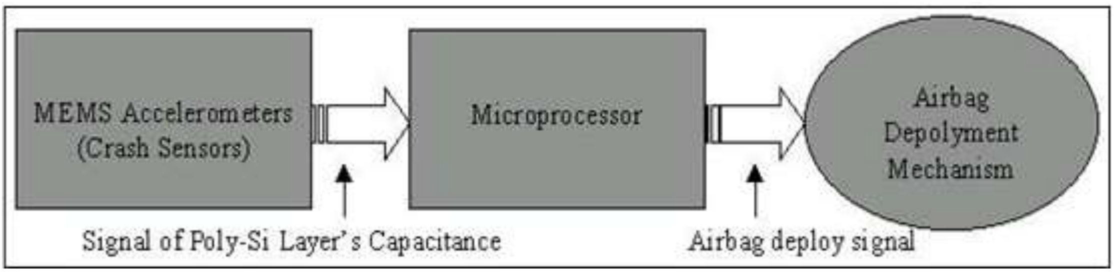


Figure 13: Flowchart representation of the airbag deployment system

In order to meet the new industrial standard of multi-directional crash sensing, two of these small MEMS crash sensors can be placed next to each other perpendicularly. Each sensor can therefore sense the acceleration forces from all four directions of the automobile. The addition of multi-directional crash sensing enables the introduction of side-impact airbags found in many new cars

6.2 Medical applications

Future uses of MEMS devices include a variety of medical devices. One of these devices is a blood gas sensor that can be inserted through a catheter 650 microns in size. It can detect the oxygen content and the pH of the blood. Other significant medical uses are the construction of neural probes to record electrical impulses on the brain. These microscopic sensors would allow researchers to place sensors close to the neurons and would allow them to map the circuits of the brain to determine how the brain truly processes and stores information. It is estimated that MEMS devices could produce a neural electronic interface. These devices could be attached directly to neurons in the brain. If the electrical impulses naturally generated by normal sensory input such as sight or hearing could be simulated by these MEMS devices, it would be possible to provide artificial sight to the blind. Other medical uses include the use of MEMS devices to combat cancer or obstructions to blood flow that produce stokes and heart disease.

6.3 Miscellaneous applications

Consumer electronics also use MEMS devices in increasing quantities. One prominent use is in the valves and orifices that are used in ink jet printers. Many of us have MEMS devices in our homes and don't even know it. Other uses include the production of chemical sensors such as smoke detectors.

7. Comparison between Conventional and Non-Conventional Micromachining

Conventional Machining	*Non-Conventional Machining*
Macroscopic chip remove	Microscopic chip remove
Direct contact between tool and workpiece	No direct contact between tool and workpiece (laser, electrode, UV ray)
Tool life is very less	Tool life is more
Mechanical energy / forces are used	No mechanical energy / forces are used (electrode, laser, UV ray)
Less capital cost	High capital cost
Finishing / accuracy is less	Very high accuracy
No need of skilled worker	Need of skilled worker
Noisy operations	Quite operations

So we choose micromachined product instead of macromachined because of high accuracy, high finishing, polish like a mirror, also it is not very expensive.

Need of Micromachining in Industry

1) Final finishing operations in manufacturing of precise parts are always of concern owing to their most critical, labour intensive and least controllable nature.
2) In the area of Nanotechnology, deterministic high precision finishing methods are of almost importance and are the need of present manufacturing scenario.
3) The need for high precision in manufacturing was felt by manufacturers worldwide to improve quality , interchangeability of components, control an longer wear / fatigue life

Also product is hundred percent as design or standard. Present day High-tech industries, Design requirements are stringment

- **Extraordinary properties of material** (high strength , high heat resistance, high hardness, corrosion resistant, etc.)
- **Complex 3D Components**
- **Miniature features**
- **Nano level surface finishing** on complex geometries

8. Conclusion

MEMS devices have evolved from laboratory curiosities of the 1980s to commercial products of today. If this growth trend continues, MEMS will very likely be the next generation of machinery to service mankind for the next century. It is predicted that the MEMS market will soar to more than $34 billion by the year 2002. **This prediction combined with the foregoing discussion on the advantages of MEMS over macro devices lead us to predict that MEMS will soon be integrated into our everyday life just as the computers have been.** From previous sections, we saw that the manufacturing process of MEMS is not the simplest, but we believe that the advantages that come with MEMS will outweigh the complexity of the manufacturing process. As MEMS researchers strive to compensate for MEMS's shortcomings, we can only expect to see more and better MEMS devices created in the coming years. The future designs and applications of MEMS are only limited by the imagination of the designers.

9. Acknowledgement

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