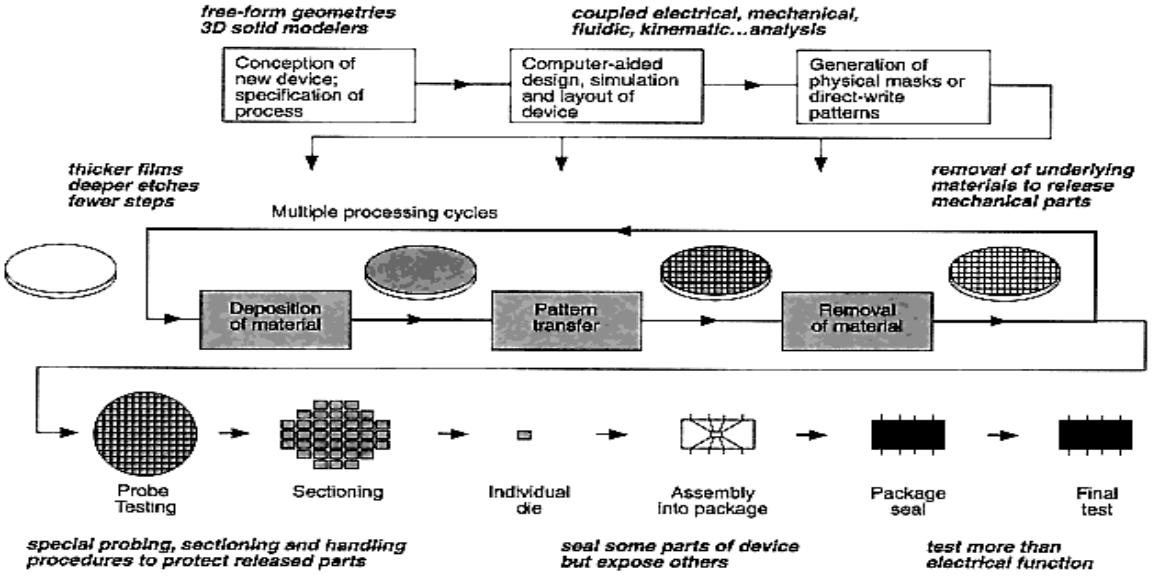
UNIT-2

MICRO ELECTRONIC TECHNOLOGY FOR MEMS

MEMS AND IC FABRICATION CYCLE:



MEMS devices all can challenge even the most sophisticated and technically advanced manufacturing line. Examples of some of the areas in which MEMS processing differences continue to challenge the norms established by both the IC fabricators and equipment manufacturers include the following.

Design Aids:

- Creation of new ICs normally entails employing fully integrated computer-aided design tools, from creation through completion.
- For MEMS, however, these tools are just beginning to be developed for commercial activities, and they exist as discrete, stand-alone programs relevant to only a small piece of the design-simulate-fabricate-validate cycle.
- One of the most challenging aspects of CAD for MEMS is the multi domain nature of the devices.

- Whereas electronic circuits function almost exclusively in the electrical domain, MEMS device operation transcends boundaries among thermal, fluid, electrical, mechanical, magnetic, and optical domains. MEMS' need for coupled solutions over several domains challenges the state of the art in CAD.

Lithography

- Whereas ICs are pushing the limits of optical lithography down below 0.35 m, MEMS are pushing the same equipment base not to smaller feature size but rather to greater depth of focus.
- Typical surface Micromachined MEMS devices can exhibit 8 microns of topography by the end of the process, compared with 0.5–1.0 micron for advanced IC processes.

Etching

- This topography generally is created using thicker deposited materials that serve as the active mechanical layers.
- Once they are patterned lithographically, these thick layers must undergo robust etch processes that have the capability to etch through the layers selectively and anisotropic ally while still maintaining critical line size dimensions and edge profiles.

Parametric Testing

- A production IC process is monitored by a regular, well-characterized set of parametric test structures.
- These structures are designed both to screen the health of the integrated process during fabrication and to act as a pre functional testing screen.
- Such a set of parametric test structures is yet to be developed, characterized, and implemented in most of the critical MEMS processes.
- Although many of the basic resistance, capacitance, and defect density test structures utilized in IC processing can be used, the mechanical nature of the materials for MEMS provides a challenge to the MEMS process engineer attempting to monitor the outcome of the fabrication run.

Functional Testing

- ➢ Functional testing of ICs generally is performed at the wafer level, and sometimes again after packaging, and is achieved mostly through the use of high-speed electronic testers capable of producing an input voltage (generally 5V or less) or current and then measuring the state of various output nodes.
- ➢ The driving forces in IC testing have been both the number of electrical inputs and outputs necessary to operate the chip (pin count) and the speed of operation.
- ➢ For MEMS testing, the pin count tends to be extremely low: a few to a few tens of pins. Voltages, however, can range into the hundreds of volts for some actuators.
- ➢ Additionally, with the exception of such notables as the Analog Devices ADXL-50 and the Texas Instruments Digital Light Processors (DLP), most MEMS devices produced today have little if any electronics integrally processed with the mechanical devices.
- ➢ This means that the tester must provide the necessary control and feedback functions as well.
- ➢ Similarly, if the device function is to sense a fluid or chemical presence, a severe ''shock," or an optical signal, full functional testing of these devices requires the presence of the appropriate environmental factor.

Packaging

- ➢ Unlike IC packaging, MEMS packaging is an application-specific task and can completely destroy a potential product's ability to reach the marketplace.
- ➢ Generic methodologies for the packaging of classes of MEMS structures currently do not exist, but they are essential to the continued growth of the field
    - MEMS packages must have the ability to meet at least one or more of the following criteria:
    - Isolate non sensing areas from sensing areas, often in harsh, corrosive, or mechanically demanding environments;
    - Not impede mechanical action, such as tilting, twisting, rotating, sliding, or vibrating;
    - Allow the transfer of fluids from one region to another;

- Allow the coupling of energy, motion, or momentum from one region to another; and
- Not transfer mechanical strain, heat, pressure, moisture, out gassing, performance restriction, and so on to the part in the package

Semiconductor sensor technologies:

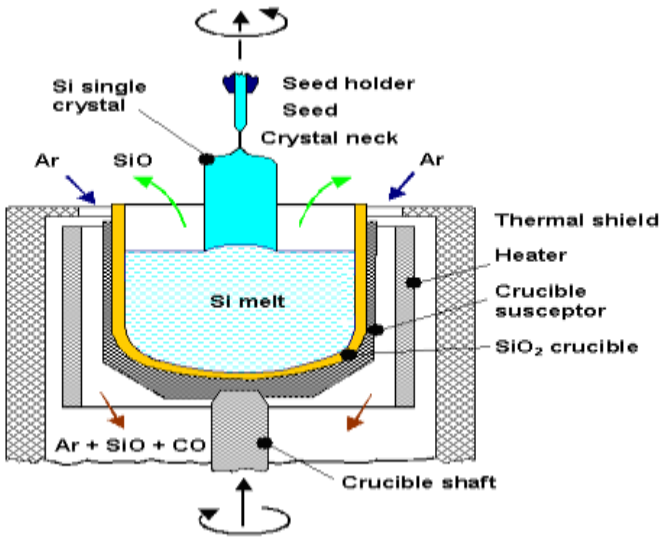
- Crystal growth
- Thin film deposition
- Pattern transfer/ Lithography
- Etching of Materials
- Doping semiconductors
- Metallization
- Bonding and packaging

➢ Now, there exists conventional methods, those conventional process or steps are taken from the VLSI technology steps.

➢ Those are crystal growth, thin film deposition process, pattern transfer lithography, etching of materials, doping semiconductors, metallization, bonding and packaging.

➢ So all these VLSI steps are also used in MEMS.

➢ Silicon is melted nearly 1400 degree centigrade.



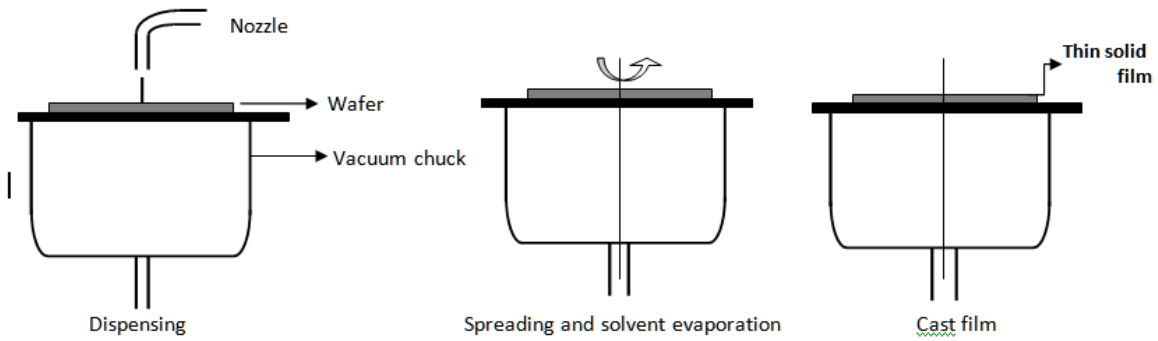
- There is a seed crystal, when you rotate it and pull upward so automatically from the seed the crystal will fall and the orientation of the crystal where it is 100 or 111 and 110, all things depends on the seed crystal.
- After slow pulling and rotating and after certain rotations you can get uniform diameter, called ingot.
- Side cooling is also very important. So when you are cooling the melt, lot of impurities by segregation they will come into the hottest zone from the cold zone.
- As a result of which if you slowly cool down, from the cool zone it comes to the hotter zone and at the end of the process, those few slices we can reject it, so the other portion will be pure. We will get the pure crystal.
- So after getting the ingot, next is to make slices. The ingot is placed by using the diamond cutter slicing is done the ingot is made into thin slices.
- After making thin slices, it is basically transported for polishing. We can use the diamond particles to get the polished single crystal silicon.

THIN FILM DEPOSITION:

FOUR TYPES:

- Spin Casting
- Evaporation
- Sputtering Deposition
- Chemical Vapour Deposition

THIN FILM DEPOSITION: SPIN CASTING



- After getting wafer, we can process the wafer. Next step is thin film deposition which is known as the spin casting technique.
- Through the nozzle we will eject some of the liquids and chuck is rotated at a high speed. So that using the centrifugal force, the solvent will spread and at the same time, the solvent will evaporate.
- A total mixture will spread and solvent will evaporate and as a result of which at the end we will get the film casted film only.
- There is some sort of spinner arrangement which is used for thick film. A photo resist coating similar kind of things is used.
- So one thing is the material must be in a liquid form otherwise you cannot spread over the entire slice.

LIMITATIONS:

- This type of **f**ilm has a high stress value.
- It will have less dense and more susceptible to chemical attack. The reason is that, when are you spreading the film over the chuck, by rotating chuck we are putting the liquid, then at the same time evaporation takes place.
- During the evaporation of the solvents so it leaves some pores. Because of those pores the film will not be highly dense and at the same time when you subsequently used those films through the pores some other gases may enter and it is susceptible to chemical attack

THIN FILM DEPOSITION: EVAPORATION:

- We will load certain wafers into high vacuum chambers which are commonly pumped with either diffusion pump or a cryo-pump.
- We need vacuum chamber to reduce the contamination from the environment.
- At the same time if you evaporate any material in vacuum its melting point and evaporation temperature will be less.
- If we use vacuum chamber, we have to use vacuum pumps and those pumps are two kinds; one is oil pump other is oil free pump.

- Now-a- days most of the vacuum chambers in VLSI laboratory, they use oil free pumps, namely the cryo-pump or molecular iron pump or sublimation pump.
- The materials will melt in the crucible and this crucible is heated by means of embedded heater and an external power supply and when you melt that crucible, then the material will be evaporated once it reaches its melting point and it will be deposited on the wafer. This is the basic working principle of a simple evaporator.

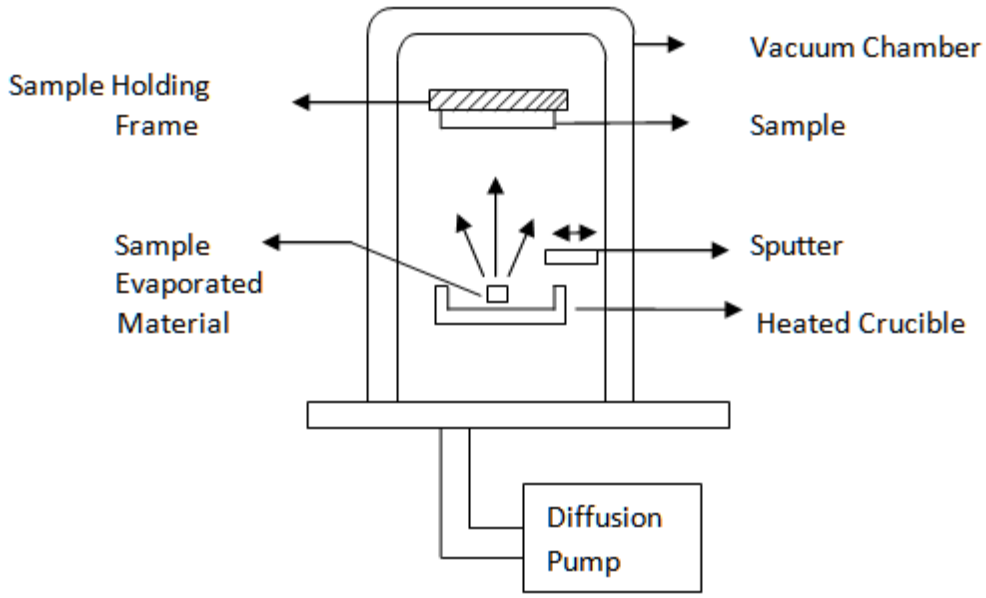


Fig: Normal Pressure Condition

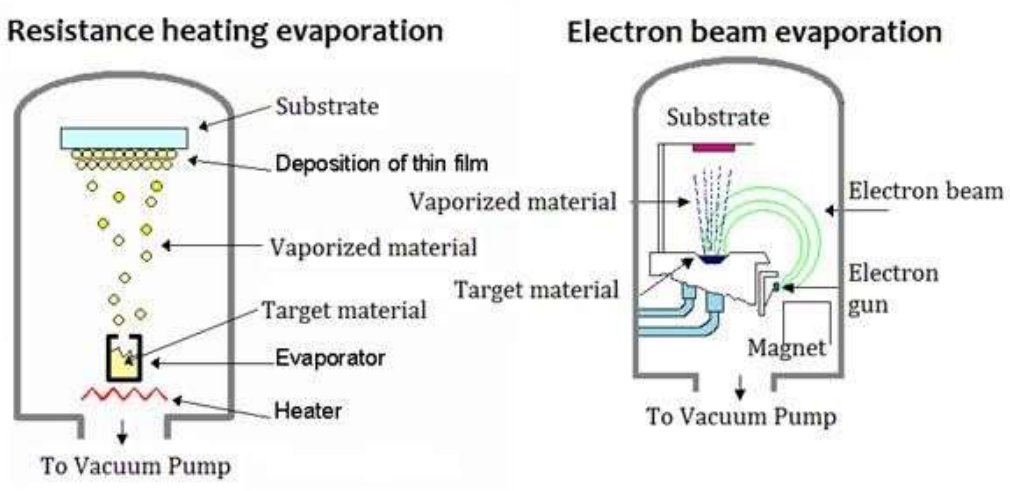
- On the vacuum chamber we will have a diffusion pump there will be a crucible and a shutter. When you raise the power of the crucible i.e heated crucible, it will start evaporation.
- If we put the shutter, those evaporated material will not deposit.
- So temperature raised at a high value, the advantage is no nucleation formulation. Because at high temperature, complete evaporation melting uniformly will occur, so there will be less chance of nucleation on the film.
- The shutter is used when we need the desired thickness of the film, then we want to switch off the power supply to the crucible.

- So we put the shutter, the evaporate will not reach on the crucible. So automatically the deposition will be stopped on the slice.
- There are three types of Evaporation techniques:

1. Resistance heated evaporation
2. Inductively heated evaporation
3. Electron beam evaporation

RESISTANCE HEATED EVAPORATION:

- In the Resistance heating technique, the material is heated until fusion by means of an electrical current passing through a filament or metal plate (Evaporator) where the target material is deposited.
- The evaporated material is then condensed on the substrate. Other ways of heating are used, such as a RF coil surrounding a graphite or BN crucible, where the material to be evaporated is fused.
- The assembly of the technique is simple and results appropriate for depositing metals and some compounds with low melting temperature.



ELECTRON BEAM EVAPORATION

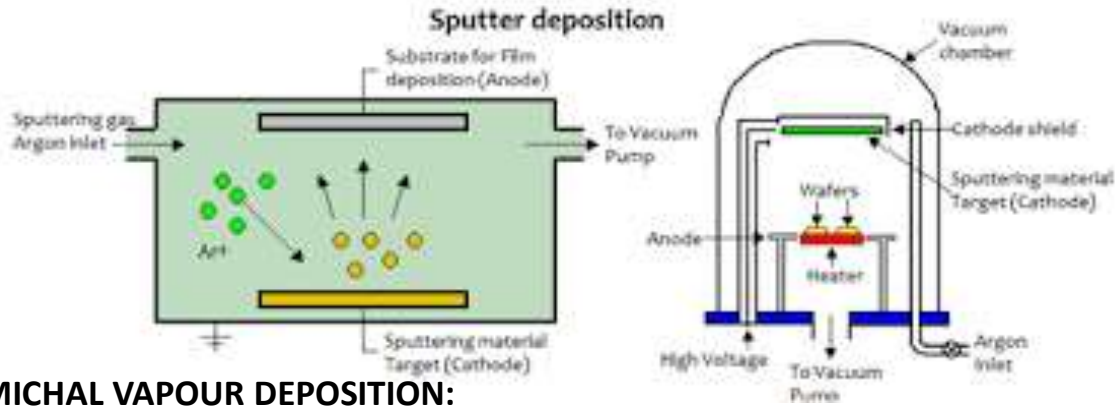
- The Electron beam heating technique is based in the heat produced by high energy electron beam bombardment on the material to be deposited.
- The electron beam is generated by an electron gun, which uses the thermionic emission of electrons produced by an incandescent filament.
- Emitted electrons are accelerated by a high voltage potential (kilovolts). A magnetic field is often applied to bend the electron trajectory, allowing the electron gun to be positioned below the evaporation line.
- As electrons can be focalized, it is possible to obtain localized heating on the material to evaporate, with a high density of evaporation power.
- This allows controlling the evaporation rate, from low to very high values, and best of all, the chance of depositing materials with high melting point (W, Ta, C, etc.).

INDUCTIVELY HEATED EVAPORATION:

- Crucible is made of boron nitride material. Because boron nitride melting temperature is very high and not only that, it is basically, the inductive coil it should not be metal.
- It is a boron nitride which is insulated.
- We have the molten charge in a crucible and the RF induction heating is used to melt this molten charge.
- So the conduction or contamination from the crucible will be there. But one advantage compared to the earlier process is that we can accommodate more charge.
- The volume of the material in the crucible is large compared to the filament which is used in resistivity operation technique.
- So we can have evaporation for longtime in case of inductively heated evaporation technique.
- So we can have a larger thickness of the deposited film on the wafer by using the inductive heated evaporation and disadvantage is mandatory use of crucible and another advantage is known no ionizing radiation.

THIN FILM DEPOSITION: SPUTTERING DEPOSITION

- Sputter deposition are methods of depositing thin films by sputtering.
- They involve ejecting material from a “target” that is a source onto a “substrate” such as a silicon wafer.
- Sputtered atoms ejected from the target have a wide energy distribution, typically up to tens of eV.
- The sputtered can ballistically fly from the target in straight lines and impact energetically on the substrates.
- The sputtering gas is often an inert gas such as argon. For efficient momentum transfer, the atomic weight of the sputtering gas should be close to the atomic weight of the target, so for sputtering light elements neon is preferable, while for heavy elements krypton or xenon are used.



CHEMICHAL VAPOUR DEPOSITION:

- In chemical vapor deposition CVD the constituents will be form of the chemical. Chemical vapor will decompose to form certain layer and it may be dielectric or metallic layer.
- If we use metal organic compound then we can get metal film deposition by using CVD technique.
- CVD technique is defined as a formation of a non-volatile solid film as a substrate by the reaction of vapor phase chemical that contains the required constituents.
- CVD is an extremely popular and preferred deposition method for a wide range of materials.

Applications:

- The different kinds of materials in using CVD technique are, the one is a polysilicon film deposition in poly crystal silicon.
- Dielectric film like silicon dioxide, silicon nitride and single crystal epitaxial growth can also have by CVD.
- Single crystal silicon is known as epitaxial formation that means ordered growth we can get using CVD technique metal film deposition.
- If we use organo-metallic compound like tungsten, molybdenum, etcetera, we can deposit using the CVD technique, and these are the various applications.

CVD Reaction mechanism:

- Now CVD reaction mechanisms involve first transport of the reacting gaseous species to the substrate surface.
- Then Absorption or chemisorptions of the species on the substrate surface.
- Because those species after transportation has to absorb.
- Third step is heterogeneous reaction catalyzed by the substrate surface.
- Next step is desorption of the gaseous reaction and products. The byproduct desorption should be there rest of the gases transport of the reaction products away from the substrate surface. So these are the 5 steps followed one by one in a CVD reaction chamber.

- So let's consider a simple thermal CVD reactor system.
- We have a gas inlet, a susceptor on which the wafers are kept and susceptors are heated.
- Susceptor means container of the silicon wafer.
- So if we heat it then gas is flown on to the surface of the wafer. In this reaction chamber at high temperature the gas will decompose and the solid material will deposit on the substrate.
- The gases used here are One is silane SiH_4 gas form, it will decompose first at high temperature SiH_2 gas plus $2H_2$ is also gas.

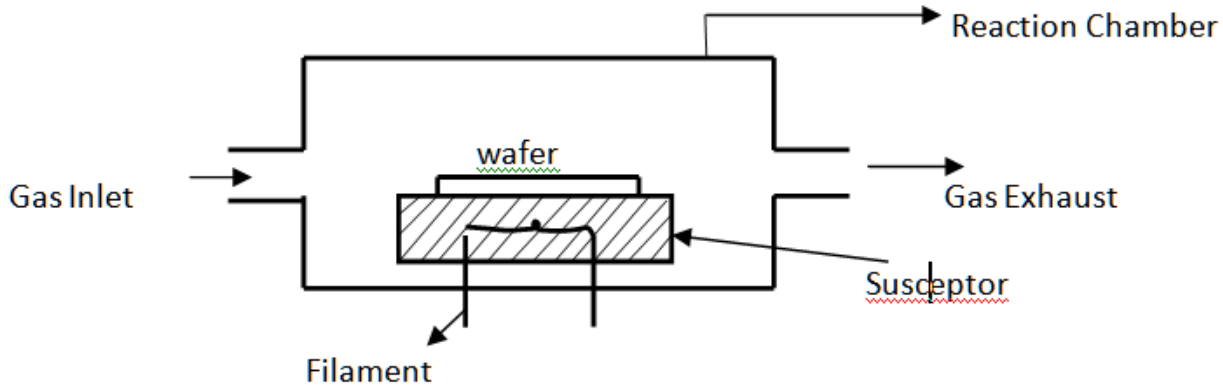


Fig: Simple Thermal CVD Reactor

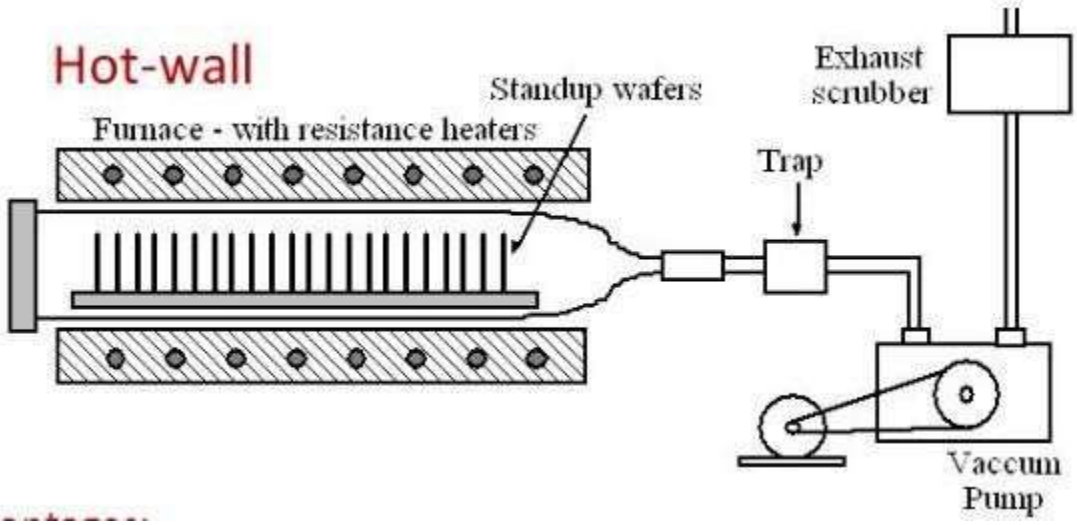
- Then SiH_2 it again changes to SiH_2 a means amorphous and then SiH_2 amorphous will give silicon solid and H_2 gas.
- So this is a reaction step. First SiH_4 at high temperature decomposes into SiH_2, then SiH_2 gas to amorphous then from amorphous SiH_2 to silicon solid and hydrogen gas.
- So after absorption, then the solid material is coming out and it is deposited. Deposition reaction occurs at the surface of the wafer.

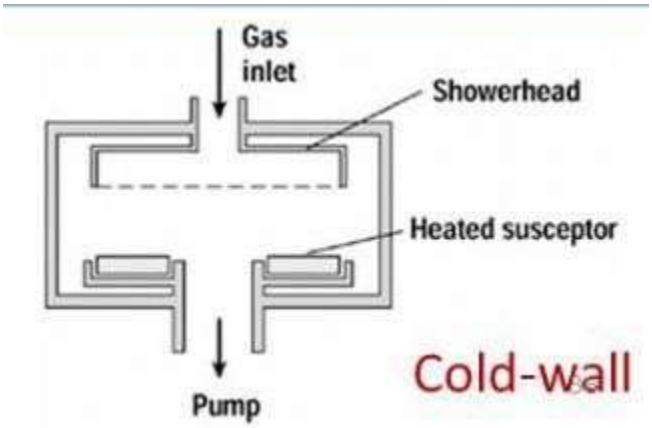
LOW PRESSURE CHEMICAL VAPOUR DEPOSITION:

$$SiH_4(g) \rightarrow SiH_2(g) + 2h_2(g) \Longrightarrow \text{at high temperature}$$

$$SiH_2(g) \rightleftarrows SiH_2(a) \text{ Then } SiH2(a) \rightleftarrows Si\ (Solid) + H_2(g)$$

(a) refers to absorbed species





- To achieve reasonable deposition uniformity the process is designed to keep the reaction strictly controlled by deposition kinetics.
- So in this ONA chamber we can stack the wafer.
- In the furnace tube, the gas inlet if we are ejecting gas means some reactant gases are coming up.
- If we do the complete reaction inside a chamber at low pressure, the nucleation of the particle will not be there.
- If the chamber pressure is high the nucleation will be there.

LITHOGRAPHY:

- Lithography is a process by which we can transfer some pattern from photographic mask to a resultant pattern on a wafer.
- The transfer of any kind of structure from mask level on to the wafer level is known as photolithography.
- In photolithography process a photosensitive polymer film is applied on silicon wafer. That photosensitive polymer film is known as photo resist.

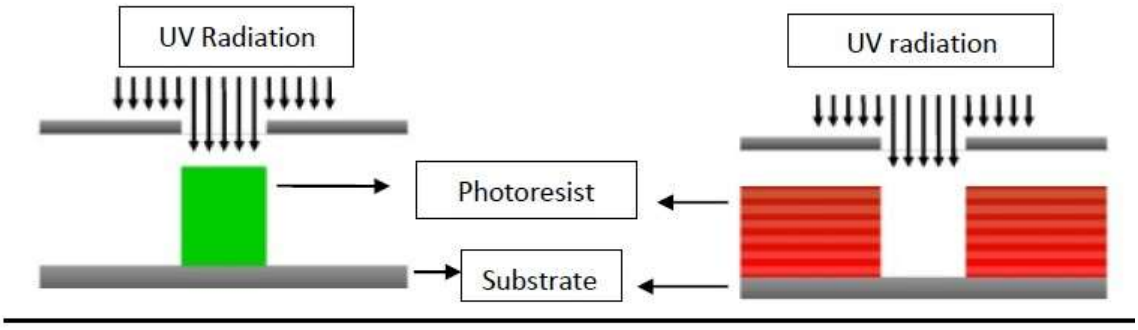


Figure : Positive photoresist and Negative photoresist

LITHOGRAPHY USING LIFT-OFF TECHNIQUE:

- Another kind of photolithography technique is known as lift-off technique.
- Lift-off technique is a special technique where we do not require the etching solution of the film.
- In some cases we may not know the etching solution. For example if you are going to design or pattern, a tungsten film or molybdenum film whose etching solution is not known.
- But we want to pattern it, so in that case the ideal technique is to use lift off technique and lift off technique is totally different.
- We pattern the photoresist instead of normal photolithography.
- First we deposit the film or silicon dioxide we grow it we first deposit metal and then we coat photoresist, then we go for patterning.

- But in case of lift off technique we do not deposit film or grow silicon dioxide. First we coat with photoresist and we get the pattern.
- Then we will deposit film, then the photoresist is first deposited for photo masking and pattern and then metal film is deposited and lifts off technique follow with the initial photo masking.

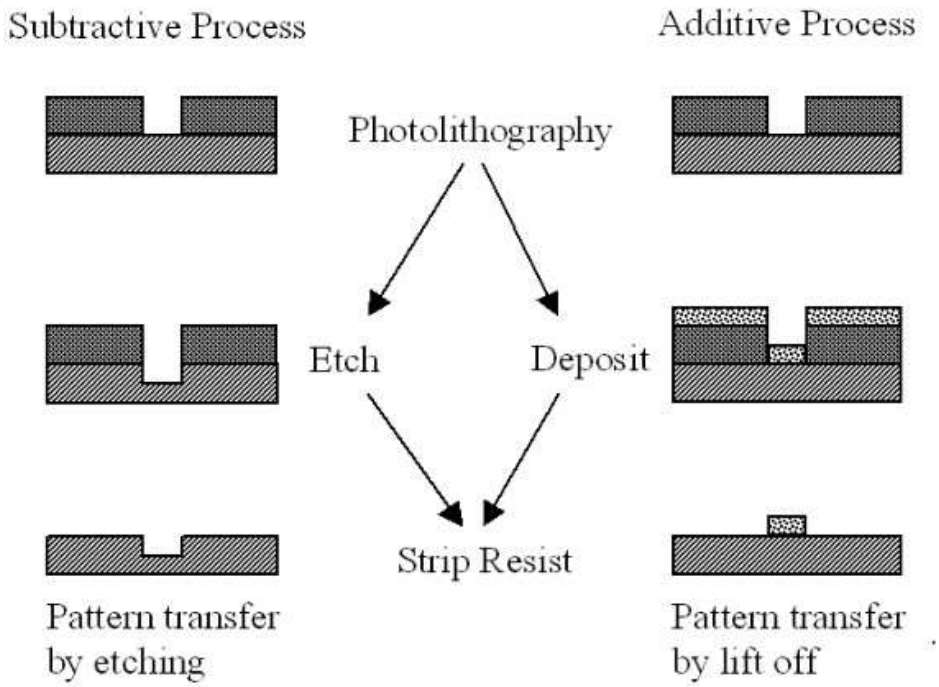
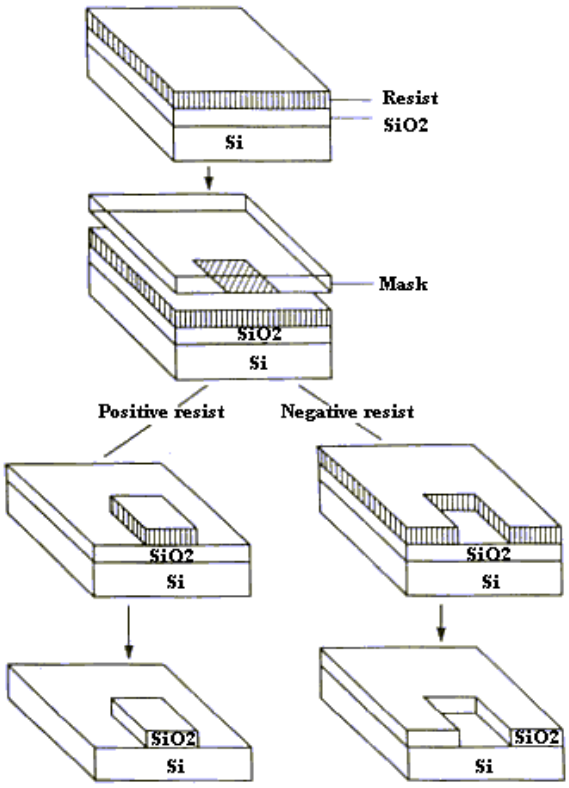


Figure: Subtractive and additive methods of pattern transfer

- Lift off technique is known as additive method of pattern transfer.
- In case of additive on the substrate instead of depositing film we first deposit mask.
- The mask means photoresist. First film may be either aluminum in case of metal or it may be silicon dioxide
- First it is coated with photoresist and then on photoresist you pattern it and after that we deposit the dissolved metal silicon dioxide.
- First photoresist is patterned, then we deposit either metal or silicon dioxide that is the film.
- We just dip the structure into a photoresist removal solution.
- The photoresist remover solution will remove photoresist from a portion and from a region it will react the first photoresist remover solution will react with the photoresist.
- As a result of two portions will be floating and that will go away and we will get this structure.
- But in this particular case you need the etching solution of the film.
- Lift off technique is used where the etching solution is not known or we know the etching solution. But that etching solution will react with the photoresist film.



ION IMPLANTATION:

Ion implantation is a process of introduction of ionized projectile atoms which we call impurity in a controlled manner into targets and the targets is silicon substrate with enough energy to penetrate beyond surface region of a single crystal substrate in order to change its electronic property.

MICROMACHINING TECHNOLOGY FOR MEMS

- Micromachining is a process of setting silicon or other material to realize 3D mechanical structures and these 3D mechanical structures may be moving or static.
- In a MEMS machining the microstructures sometimes move. It is basically a process by which you can get a 3D structure.
- In MEMS the structure will be 3 dimensional, so that we can make certain actuators or sensors in the complete micro system.

Etchant Characteristics:

1) Direction dependency: If we etch silicon, etch rate of the silicon is not uniform in all direction. If we dip the silicon wafer into the etching solution, the vertical etch rate, a lateral etch rate will in the silicon bulk we will not be the same. If it is same, then this is known as the isotropic etching. If it is not same, then this known as anisotropic etching. That means etch rate depends on the direction. The etching is also depended on crystallographic orientation. That means the etch rate of 1 0 0 plane of silicon is not same as etch rate of 1 1 1 direction of silicon; crystal plane of silicon. So when the etch rate of different crystal planes are different, then that is also known as anisotropy or crystallographic anisotropy of etching.

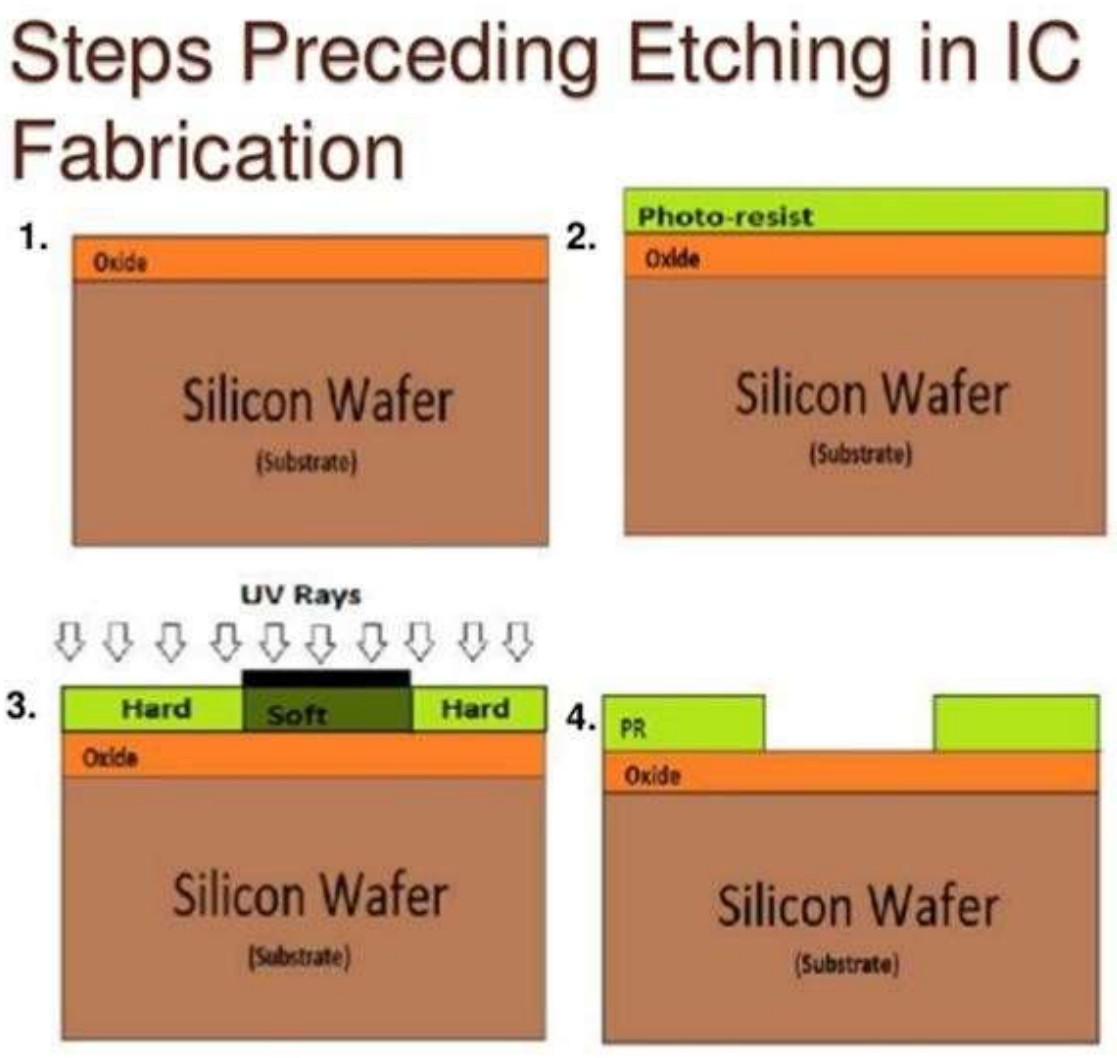
2) Etch rate: Etch rate also varies with the concentration of the etching solution. It varies with the temperature and many other things and this etch rate varies from 0.25 to 40 micrometer per minute. In many cases we have to control the etch rate. So we need some times the etch condition or etch bath temperature or mechanical stirring all has to be perfect means has to be standardized to get certain etch behavior.

3) Anisotropic etch rate ratio: The etch rate of 1 0 0 plane of silicon is not same as etch rate of 1 1 1 direction of silicon when the etch rate of different crystal planes are different, then that is also known as anisotropy or crystallographic anisotropy of etching. For anisotropic etchant this may vary from 1 is to 1 which is the isotropic to 400 is to 1 also depending on which type of the

etching solution we are going to use and what are the conditions of etchant bath we are maintaining .

4) **Etch selectivity:** If we want to etch a certain region, we have to passivation the other region which we don't want to etch. We are putting some passivation layer and that layer will not be affected by the etchants or etching solution which is known as selectivity. So this selectivity is very important aspect when you want to make some microstructures and that means, it depends selecti- vity is basically coming from the material properties as well as the etching chemical properties.

5**) Temperature of Etching: T**he etching bath temperature has an important role on the etch characteristic. In most of the silicon or silicon dioxide etchants, they depend on the temperature of the bath. In many cases if the temperature of the bath increases, its rate also increases. So etch rate depends on temperature also. The process is known as micromachining of silicon.



ETCHING OF ELECTRONIC MATERIALS:

- Etching is a process by which patterns is transferred by selective removal of un-masked portions of a layer which are masked, those portions will not be etched, which are un-masked; those portions will be removed selectively in the solution.
- There are two types of etching:

  1) Dry etching and

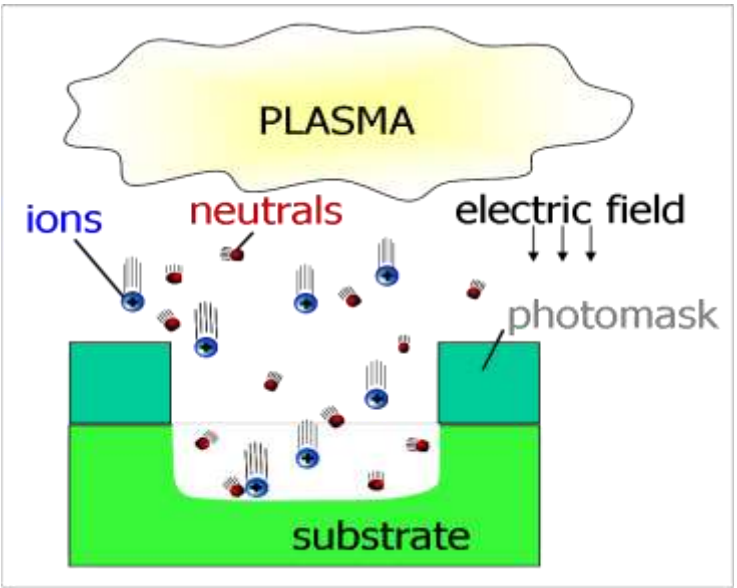
  2) Wet etching.

WET ETCHING:

- Wet etching is a practical alternative for a high-throughput flexible production process
- Throughput is a parameter which always you have to keep in mind when you are going for in industrial process
- Throughput means in a certain step, certain etching process, how many wafers you can etch at a time. So in case of wet etching the number of wafers may accommodate in the etch bath depends on the size of the etching chamber and it can be very large ranging from 50 to 100 wafers can be etch at a time in case of wet etching.

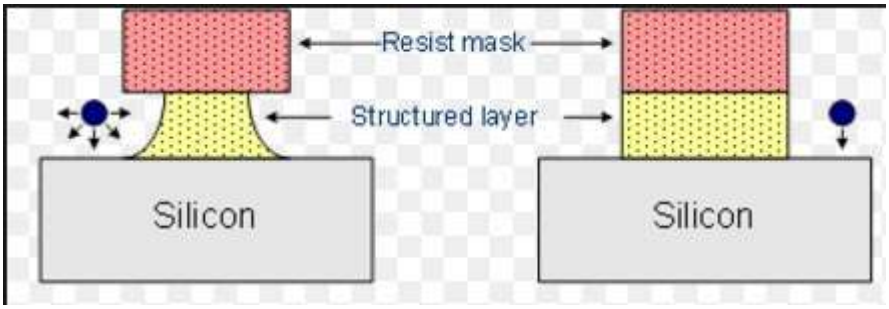
DRY ETCHING:

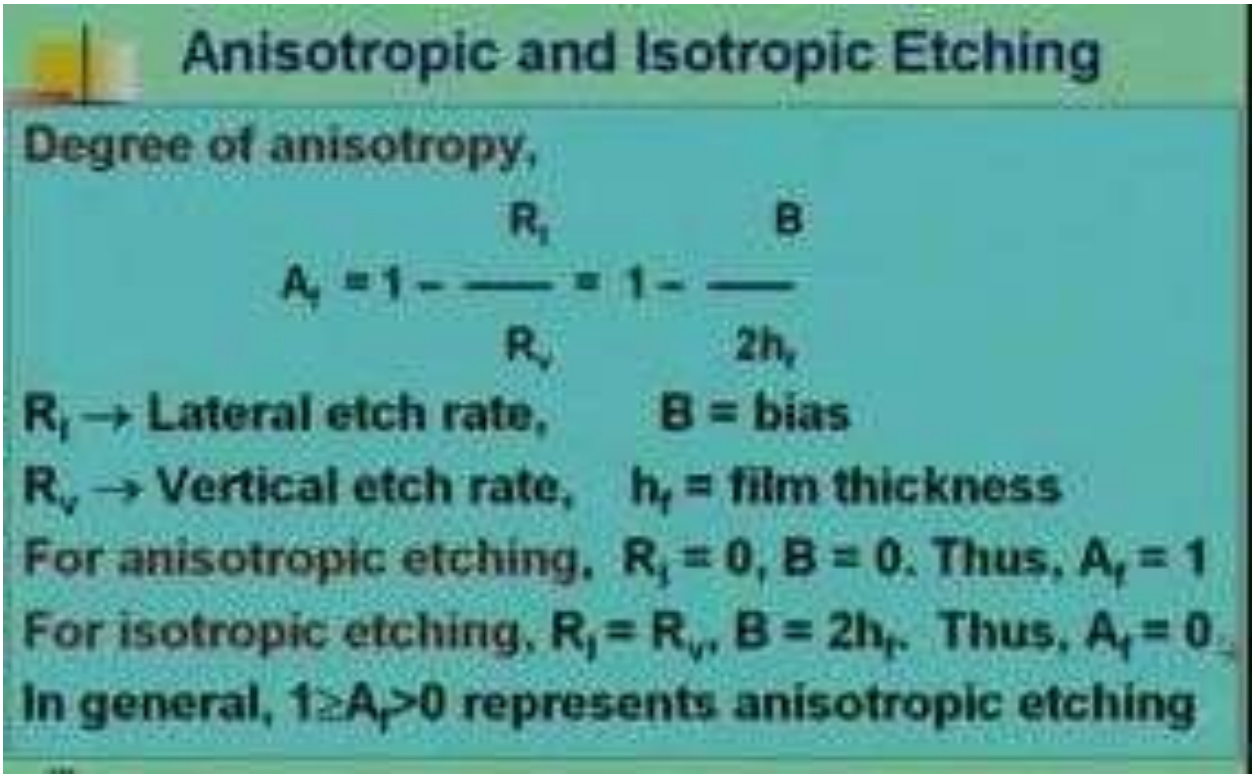
- Dry etching produces gaseous products, and these products should diffuse into the bulk gas and be expelled through the vacuum system.
- There are three types of dry etching (e.g., plasma etching): chemical reactions (by using reactive plasma or gases**)**



ANISOTROPHIC AND ISOTROPHIC ETCHING:

- Anisotropic etching, basically the etch rate etching is not done in all direction uniformly.
- That means no etching in lateral direction and the pattern is transferred with perfect fidelity.
- On the other hand the isotropic etching case vertical and lateral etch rates are always equal. That is etch rate is independent of direction.
- In the diagram, one is anisotropic, there is a layer, mask, another is the film or structural layer and the last layer is the substrate.





MICROMACHINING PROCESS

SILICON MICROMACHINING:

There are two types of silicon micromachining:

1. SURFACE MICROMACHINING
2. BULK MICROMACHINING

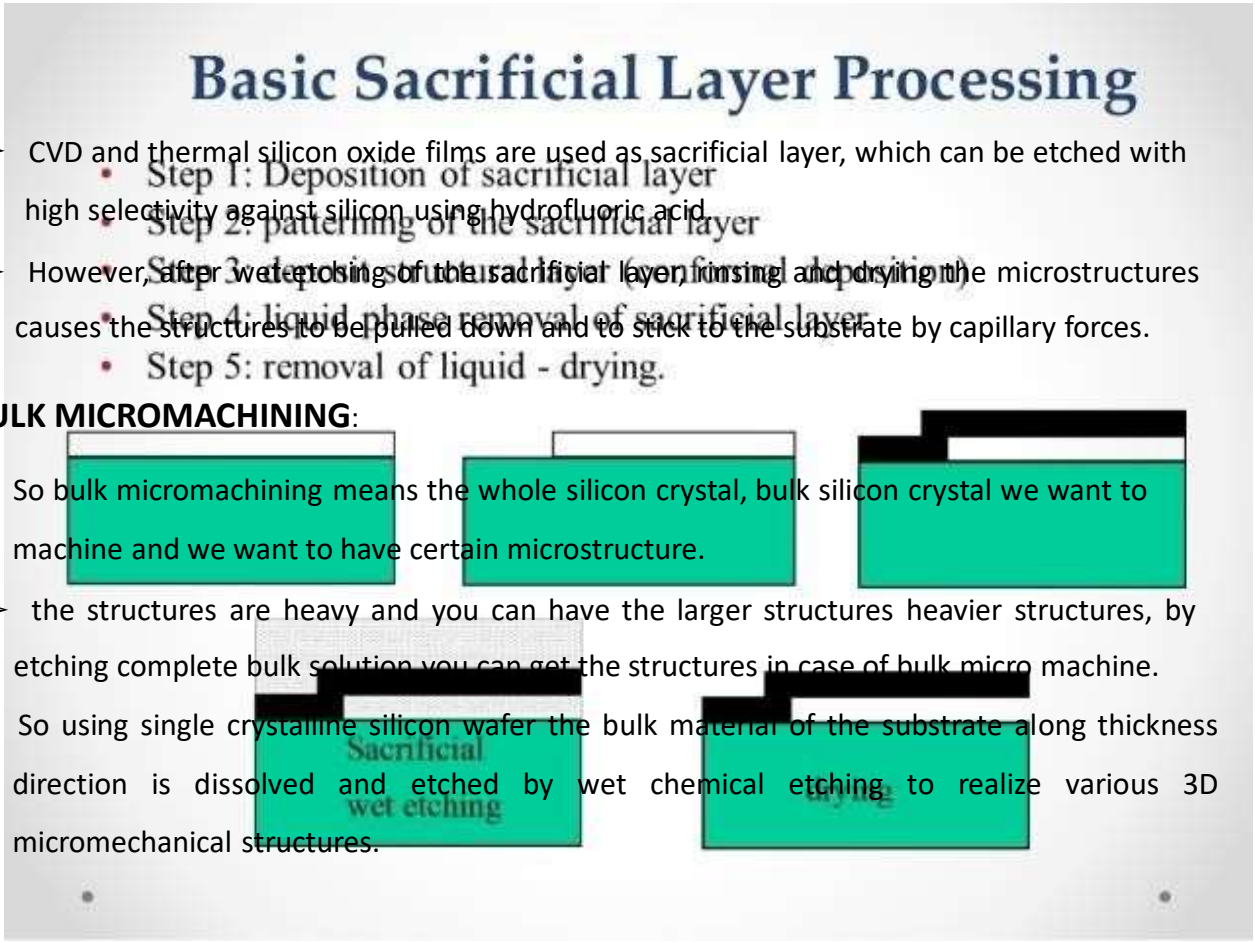
- ➢ Bulk and surface micromachining are processes used to create microstructures on microelectromechanical MEMS devices.
- ➢ While both wet and dry etching techniques are available to both bulk and surface micromachining, bulk micromachining typically uses wet etching techniques while surface micromachining primarily uses dry etching techniques.

SURFACE MICROMACHINING:

- ➢ Surface micromachining means on the surface of the silicon wafer you want to have certain microstructures, not the whole bulk material is used.
- ➢ The main features of the surface micro-machining technology are the small microstructure dimensions and the opportunity to integrate micromechanics and microelectronics on the same chip.
- ➢ A processing sequence using polysilicon as micro-structural material and silicon dioxide as sacrificial layer is shown in the figure below.

Key challenges in fabrication of microstructures using surface micromachining:

- ➢ Control of stress and stress gradient in the structural layer to avoid bending or buckling of the released microstructure
- ➢ High selectivity of the sacrificial layer etchant to functional layers
- ➢ Avoidance of sticking of the released microstructure to the substrate



- CVD and thermal silicon oxide films are used as sacrificial layer, which can be etched with high selectivity against silicon using hydrofluoric acid.
- However, after wet etching of the sacrificial layer, rinsing and drying the microstructures causes the structures to be pulled down and to stick to the substrate by capillary forces.

BULK MICROMACHINING:

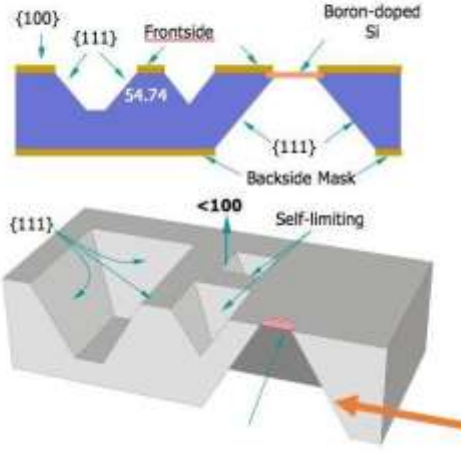
- So bulk micromachining means the whole silicon crystal, bulk silicon crystal we want to machine and we want to have certain microstructure.
- the structures are heavy and you can have the larger structures heavier structures, by etching complete bulk solution you can get the structures in case of bulk micro machine.
- So using single crystalline silicon wafer the bulk material of the substrate along thickness direction is dissolved and etched by wet chemical etching to realize various 3D micromechanical structures.

Bulk Micromachining

- Mechanical properties of bulk silicon is preserved
- Device thickness is controlled by etching/ diffusion
- Alignment required for top and bottom side of wafer

Bulk micromachining

- Long etching processes
  - Silicon Nitride used to mask
- Wet etching
  - Isotropic



Isotropic etching

Anisotropic etching

BULK MICROMACHINING ETCHING TECHNIQUES:

There are various chemical etchants we use for bulk micromachining

- EDP etching
- KOH etching
- TMAH etching
- LIGA

EDP (ETHYLENE DIAMENE PYROCATECHOL) ETCHING:

ADVANTAGES:

- It is highly selective over materials like silicon dioxide, silicon nitrite, chromium and gold. So all these three materials can be used for masking purpose.
- Etch stop technique is very simple

FEATURES OF EDP:

- Etch rate of the silicon material depends on temperature composition of etchant and density of atomic bonds on exposed silicon plane.
- Orientation size and shape of the oxide opening on the wafer surface determine the type of hole formed.
- Very thin membrane of uniform thickness can be created by forming heavily boron P plus layer. That means here the P plus boron layer will act as an etch stop layer.

COMPOSITION OF EDP:

- Composition of EDP etching is:

  50 mole percent water,
  40 mole percent ethylene diamine and
  4 mole percent pyrocatechol

- Etch temperature we used normally used here in 100 degree centigrade.

- Etch environment is nitrogen etch rate of 1 0 0 silicon plane is found to be 25 micrometer per hour

KOH (POTASSIUM HYDROXIDE) ETCHING:

ADVANTAGES:

- Easy to handle
- Smooth edge profile
- It attacks aluminum metal, so aluminum metal or in some cases gold metal also cannot be used for passivation.
- Much higher <100> to <111> etch rate ratio
- SiO2 etch rate in KOH is higher than EDP
- KOH is much useful to etch deep trenches in <110> silicon plane

ANISOTROPIC KOH ETCHING OF SILICON:

- KOH concentration is used 10 to 50 percent of KOH solution is used for the micromachining of silicon.
- In KOH we sometimes add some organic chemical which is isopropyl alcohol and that isopropyl alcohol will help you getting more selectivity.
- KOH etch selectivity of 1 1 0 over 1 1 1 crystal plane is much higher of the order of 500 than that of EDP.
- As etch selectivity over silicon dioxide is less than 500 at various concentrations of KOH silicon dioxide etch mask is not adequate for long etching
- Silicon nitride is an effective masking film for KOH etching.

TETRA METHYL AMMONIUM HYDROXIDE (TMAH) ETCHING:

- The TMAH basically is an organic etching solution and this particular etchant has one biggest advantage is that, it does not attack aluminum.
- That means after complete metallization of the silicon wafer, that means interconnect lines has been pattern then you go for micromachining.
- So the aluminum fine lines which are used for interconnection will never be attacked or never be disturbed.

- Because of that reason, we say the TMAH is CMOS compatible micromachining etchant solution. Many cases now days that the sensor and the signal conditioning circuits are fabricated side by side and they are integrated together.

- Etch selectivity to masking layers even with aluminum film degree of anisotropy and relatively low toxicity.
- Because it is an organic chemical etchant, so it is not toxic also, that is another advantage.
- So we always try to avoid the toxic etchant because of the health point of view.

CHARACTERISTICS OF TMAH ETCHING:

- Influence of TMAH concentration is there on etching process.
- Quality of silicon etched surface. Because if you go for the VLSI realization along with the sensor realization. So silicon etch surface quality should be extremely good.
- Smooth surface you have to get for various reasons selectivity to aluminum lower 1 0 0 to 1 1 1 etch rate ratio.
- Anisotropic etchant for silicon, anisotropic etchant means it is like selectivity over the different crystallographic plane, low toxicity, highly selective to oxide and nitride compared to KOH.
- The selectivity to oxide and nitride is more in TMAH compared to KOH. So that means you can go for either oxide masking or nitride masking or aluminum masking or gold masking. You have lot of freedom if you use TMAH.
- But the total standardization technique of the TMAH etching in silicon is not very simple is not that much easy.

TMAH ETCHING:

- The surface roughness increases with the decrease of TMAH concentration.
- The TMAH concentration increases the etch rate falls. That means at low concentration TMAH the etch rate is higher which is normally not true in many of the etchant solution.
- But at the same time if we decrease the TMAH concentration surface roughness increases.
- If we need high etch rate ratio and good surface we have to use silicic acid and ammonium persulphate as a dopant into the TMAH solution.

➢ Basically silicic acid, ammonium persulphate has got different purpose or different action on total TMAH etching process.

Anisotropic Etching Characteristics

Etchant	Temperature (°C)	Etch rate (μm/hour) Si(100)	Si(110)	Si(111)
$KOH:H_2O$	80	84	126	0.21
KOH	75	25-42	39-66	0.5
EDP	110	51	57	1.25
$N_2H_4H_2O$ (Hydrazine)	118	176	99	11
NH_4OH	75	24	8	1

Other Alkaline Silicon Etchant

- Amoninum hydroxide (NH_4OH)
- Sodium hydroxide (NaOH)
- Hydrazine ($N_2H_4.H_2O$)

All alkaline etchants affects metal interconnection lines

- EDP does not attack gold but it does attack Al
- Tetramethylammonium hydroxide (TMAH) does not attack Al and is a promising Si etchant with Al masking layer

LIGA MICROMACHINING TECHNIQUE:

- ➢ LIGA is a bulk micromachining. In this particular LIGA process you can get very high aspect ratio 3 dimensional structures.
- ➢ Basically many of mechanical structure which is used in watch are now being made with the help of LIGA micromachining process.
- ➢ The complete name of the LIGA is lithographie galvanoformung and abformung. These are German words and it English equivalent is “lithographie” is lithography.
  Galvanoformung is “electroplating” and “abformung” is a molding. So LIGA basically lithography, electroplating and molding.

Advantages:

1) Ability to create 3D structures as thick as bulk micromachine devices while remaining the same degree of design freedom as surface micromachining.

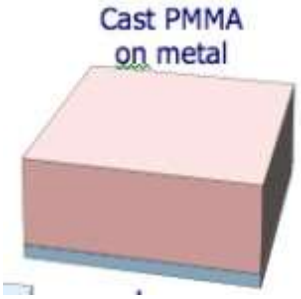
2) Design freedom of surface micromachining and etch depth is similar to bulk micromachining.

3) Microstructures with feature sizes of several microns have been made with a thickness in excess of 300 micron with the LIGA process.

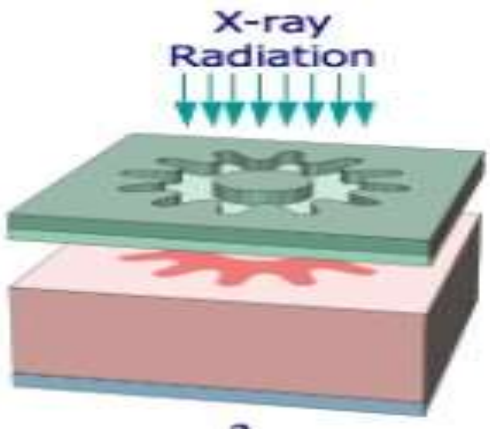
4) More than 3 micron thickness is easily obtained by the LIGA technique.

PROCESS STEPS:

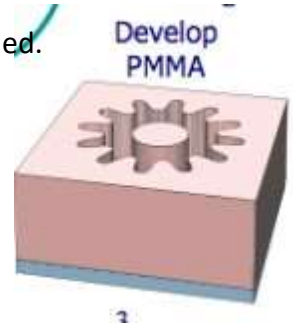
Step-1: First we take a substrate on that we will lay electrically conductive layer and some metal plating has to be done at bottom. After that we coat photo resist of thickness is 300 to 500 micrometer. A very high viscous photo resist is to be used and PMMA polymethyl methacrylate is one such resist, SU8 is another resist which is used for LIGA process. So that a photo resist will give you a thick layer of the film after spinning and drying.



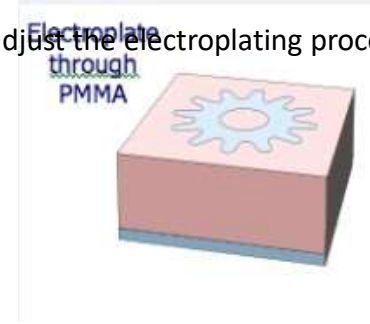
Step-2: Through the mask we have to radiate the PMMA with x-ray radiation. So x-rays are collimated and it will penetrate to the thick resist in well-defined sidewall. The x-radiation will penetrate through that thick layer and complete reaction that is polymerization will take place.



Step-3: After exposing next step is developing. So we develop the desire develop the photo resist after exposing. Then during development we can use either positive or negative photo resist in this positive photo resist is used. So where we expose, those portion will dissolve. The portion where exposed by x-ray radiation has been dissolved by developer solution of the PMMA then the hole has been formed.

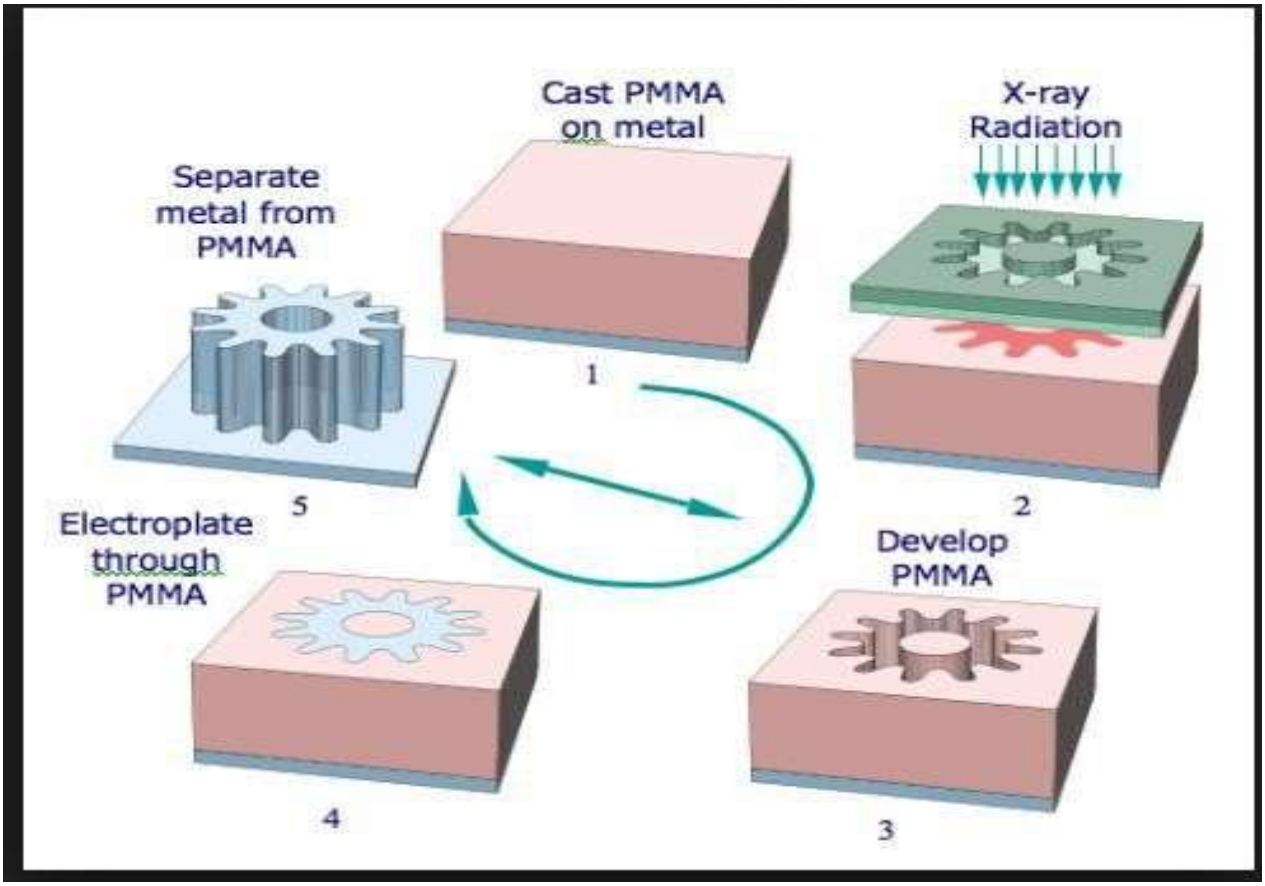


Step-4: Metal electroplated on the exposed conductive substrate surface. So metal is electroplating. The bottom is a conductive layer. Electroplating will help us depositing that particular metallic film into the groups as higher thickness. Long time electroplating we can increase the etch rate, we can adjust the electroplating process based on the variants.



Step-5: The photo resist is removed only the metallic structure is there which is basically fixed on this bottom metal plate. The sacrificial techniques are combined with the basic LIGA process

to create partially freed flexure suspended structures or completely freed devices which can be used as a mold.



ETCH STOP TECHNIQUES

INTRODUCTION:

- Etch stop is a very important aspect in making microstructure
- MEMS in many cases we need membranes and flexures or cantilevers of certain thickness and that thickness varies in case of surface micromachining may be 2 micron, 3 micron in case of bulk micromachining.

- Sometimes we need membrane of 10 micron, 20 micron or 30 micron and thus, those 10, 20 or 30 micron is coming from the bulk thickness of the wafer which is nearly 300 to 500 micrometer depending on the wafer size.
- If it is a 2 inch diameter wafer, the thickness is nearly 280 to 300 micrometer.
- If it is a 4 inch diameter wafer, the thickness of the wafer is nearly 500 micrometer.
- If it is a 6 inch or 8 inch then you will get further more thickness of silicon wafer
- So from that thickness it has to come down to 10, 20 or 30 micrometer.
- So somewhere we have to stop the etching process.

- Two ways to stop the etching process
  1. Mechanical process
  2. Automatic process

Mechanical process:

- Observe the time, if you know the etch rate of that film basically silicon, here if you know the etch rate of silicon in that particular etching solution, then you can note down time how much time you will etch.

Automatic process:

- It will continue etching but after certain point, that point has to be decided by electronically or electrically. So automatically they will stop. So out these two techniques obviously you go for the second one which is automatic.

TECHNIQUES:

- Etch stop basically which will defined as a region where wet etching or dry etching tends to slowdown or halt is called is etch stop.
- So it may not be completely stopped but slowdown in a drastic way so that is also called etch stop.
- Silicon membranes are usually fabricated using etch stop technique of a thin heavily boron doped layer which can be epitaxial grown or formed by diffusion or implantation of boron into a lightly doped substrate.
- Etch stop techniques are two types:
  1. Doping selective etching (DSE)
  2. Bias dependent etching
  3.

DOPING SELECTIVE ETCHING:

- That is heavily doped regions etch more slowly, that is the basic principle of doping selective etching
- Why heavily doped region etches more slowly?
- The reason is heavily boron doping, if you go doping level for boron of the order of 10 to the power 19, nearly then the lattice constant of silicon decreases.
- If the lattice constant of the silicon decreases, then automatically a strain will be developed inside the lattice.
- So because of that introduction of strain inside the crystal, those atoms cannot be etched. That is the basic principle of the DSE, means doping selective etching and that strain or reduction of lattice constant will occur.

BENEFITS OF DSE:

- High boron etch stop are independent of crystal orientation because, if you dope the layer with high concentration of boron the reason of stopping etch is only the formation of strain inside the crystal.
- We will get surface finished very smooth, there smooth surface finished

LIMITATIONS OF DSE:

- High levels of boron introduce mechanical stress into silicon and may cause buckling or even fracture in a diaphragm or double clamped structure.
- Not suited to stress sensitive microstructures that could lead to the movement of structures without an external load
- If you dope the layer with high boron concentration, in that layer is very difficult to fabricate
- Highly doped boron layer you cannot make resistance because whole membrane is highly doping, then you cannot get p-diffused resistance you have to go for n-diffused resistance, n-diffuse resistance Piezoresistive coefficients is less compared to p.

ECE (ELECTRO CHEMICAL ETCH STOP TECHNIQUE) / BIAS DEPENDENT/SELECTIVE ETCH STOP TECHNIQUE (BSE):

- Electrochemical etch stop technique, it's another name is bias dependent etching or bias selective etching

- Now is an electrochemical cell the picture is shown here and in electrochemical cell, this is one should be the cathode, another will be anode.
- So here silicon is anode and the platinum is a cathode and you have applied a voltage V_A here.
- So if you apply voltage V_A and this is the Hydrofolic acid solution. So this forms an electrochemical cell.

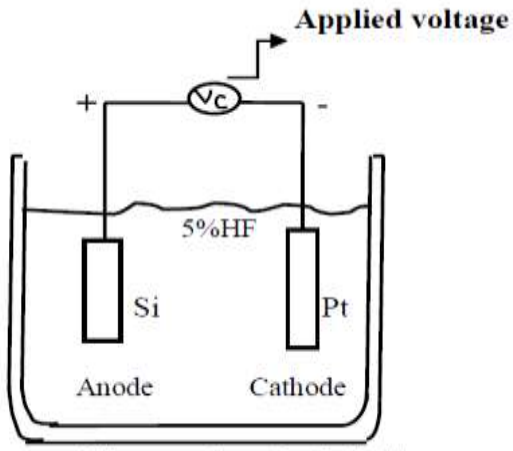


Figure : Electrochemical Cell

- If we apply a positive voltage in the silicon(accumulates holes at the silicon surface) initially it will form an oxide and that oxide is dissolved in the solution, clear which means bias voltage at the silicon has some control on etching process.
- The Hydrofolic acid can't etch silicon, it will etch silicon dioxide.
- Silicon first automatically converted into layer of dielectric silicon dioxide then it is etched by etching. It is a bias dependent etching; the whole process is depending on the bias.
- Application of positive bias voltage on the silicon amount of voltage we are applying, how much holes are accumulated at the surface dependents on bias.
- Hydrofolic acid is basically we know is an isotopic agent.
- It is not crystallographic dependent agent.
- So normal in micromachining or MEMS we use the anisotropic crystal etching which is crystallographic dependent etching that is a KOH.

FABRICATION OF SILICON MEMBRANE USING EDP ETCHING:

- Growths of defect free thermal silicon dioxide. The thermal silicone dioxide will act as a masking material.
- A removal of front side oxide for boron diffusion protecting the back side etching.
- Go for lithography and open windows and there you diffuse the boron atom to get a highly doped region boron diffusion on the front side of the wafer to form etch stop layer.
- Boron concentration 7 to 10 to power of 19. So that is why I wrote it 10 to the power 19 to 10 to the power 20 atom per cc and in that doping level the resistivity will be 2 to 3 ohm per square. So that is resistivity in that doping concentration.
- Opening of window at back side of wafer by photolithography. Front side, you have diffuse boron.
- Etching of silicon in EDP solution through windows.
- This window SiO_2 acts as a mask. This SiO_2 will act as a mask whose etch rate in EDP is nearly 20 nanometer per hour. This oxide, it is 20 nanometer per hour.
- Compared to 20 to 30 micron per hour for silicon, so here it will etch 20 to 30 micron per hour. But here the silicon dioxide with 20 nanometer per hour, high selectivity of a silicon dioxide, so in this way you can get the membrane.

SURFACE AND QUARTZ MICROMACHINING

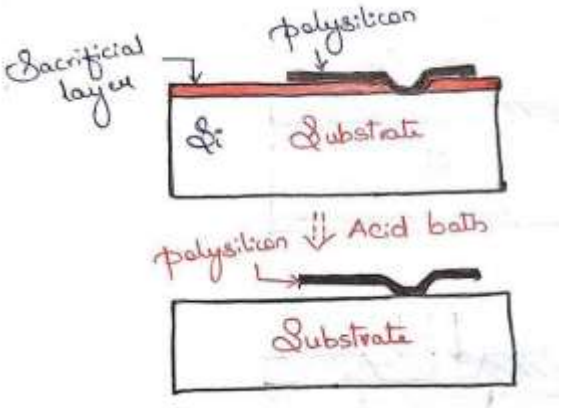
INTRODUCTION:

- Today we will discuss on surface micromachining of silicon as well as quartz micromachining.
- MEMS materials that quartz is also an important MEMS material lot of sensors are fabricated using quartz because it is a very good piezoelectric material.
- So if you use quartz in MEMS sensor, you have to have some technology on micromachining of quartz.

SURFACE MICROMACHINING:

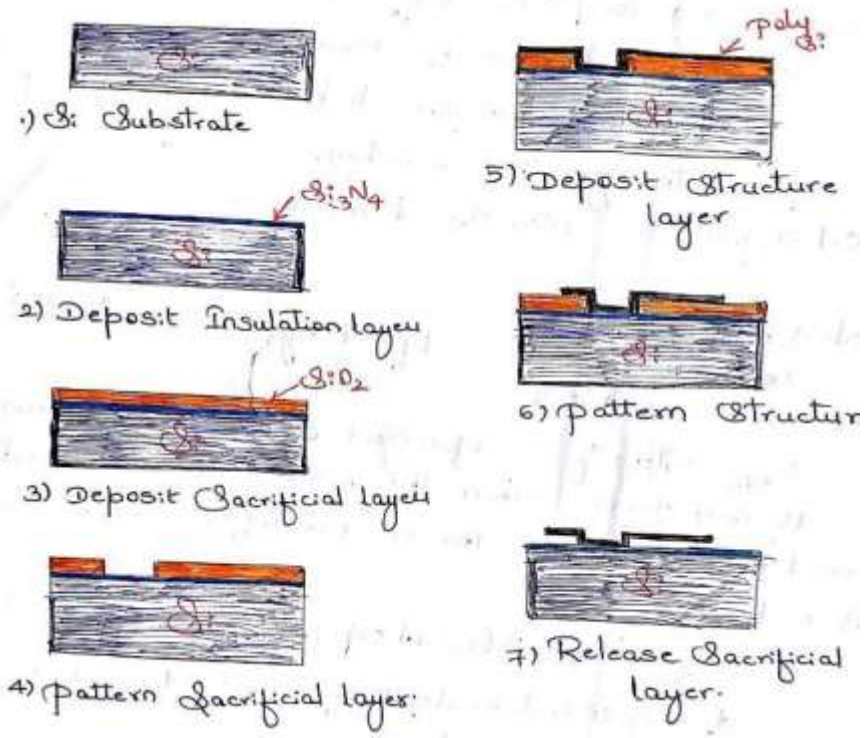
- Surface micromachining is a direct extension of semiconductor manufacturing technology.

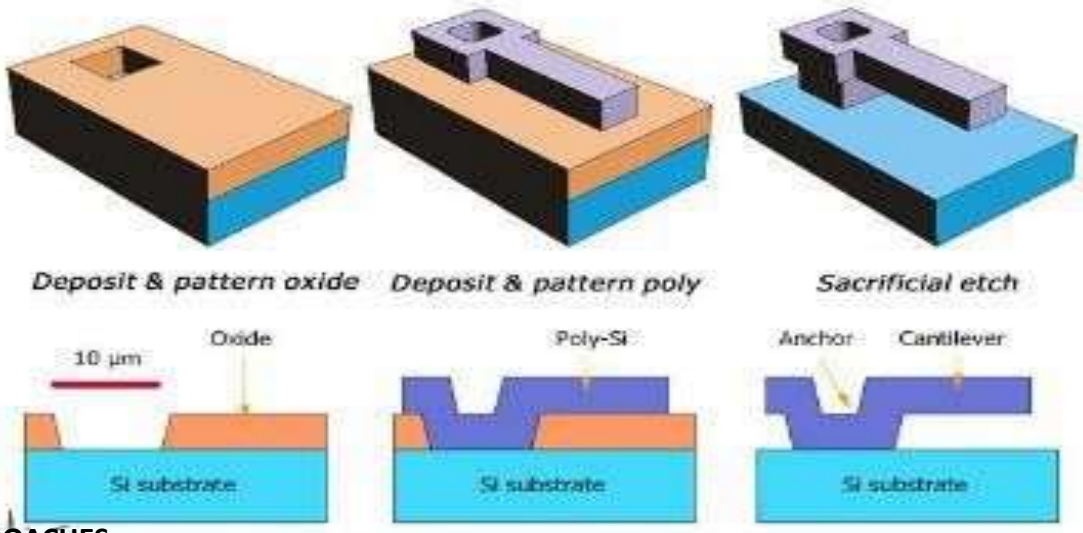
- Direct extension means, it is coming from the normal etching which is used in VLSI processing.
- Bulk micromachining is not a direct extension because in normal VLSI processes do not require the etching up to 300 micron, 400 or 500 micrometer.
- But surface micromachining etching is in the range of few microns 1 micron or 2 microns; in some cases may be 500 angstroms also.
- Manufacture devices an order of magnitude smaller than bulk micromachining on the order of 50 to 100 micrometer that means the order of the manufacturing devices can made much smaller.
- Same wafer surface microelectronics.We are going to use same wafer surface for making the structure as well as the microelectronic device means transistor, diodes, etc. It enables integration of microelectronic and micromechanical components
- Basically sensor and signal conversion circuit can be integrated very easily in case of bulk micromachining and in surface micromachining process, because of a sacrificial layer.
- There are two kind of layer in case of surface micromachining; structural and sacrificial layer. Silicon dioxide or photo resist are usually used as sacrificial layer.



- Based on depositing and etching structural and sacrificial film the surface micromachining depends.
- After deposition of thin film, sacrificial layer is etched away leaving a completely assembled microstructure, maximum possible thickness on the microstructure is limited to that of the deposited film.

- On silicon substrate, first the sacrificial layer which is silicon dioxide, that is either it is grown or deposited. Then we pattern sacrificial oxide after patterning, we will get U pattern.
- Polysilicon layer will be the structural layer. Now we pattern Polysilicon using photolithography.
- Put whole thing in acid bath, if we put in it will etch the sacrificial oxide and the isotropic etching is done. If we put in acid bath, it is not direction dependency like silicon etching means 1 1 1, 0 0 0 or 1 1 1 on 1 1 0.
- This anisotropy of etching depends on crystallographic plain orientation and anisotropic etching. Because we are etching silicon dioxide whose etching solution is buffered hydrofluoric acid.





APPROACHES:

- The common approaches to the making of micro electro mechanical system devices using surface micromachining,
- One is sacrificial layer technology, Second is wet anisotropic etching, Plasma Etching
- When we want etching from the side, that is vertical etch & lateral etch, wet etching is much favored in making surface micromachining devices.
- In normal liquid etchings are mostly the isotropic etchings. And third one is plasma etching. which are isotropic in nature but if we use reactive ion milling etching.

SACRIFICIAL LAYER TECHNOLOGY:

- First step is a deposition and patterning of a sacrificial silicon dioxide layer on the substrate.
- Next step is deposition and definition of a Polysilicon film. While depositing the Polysilicon film, then removal of the sacrificial oxide by lateral etching in hydrofluoric acid.
- If we need select hydrofluoric acid is a choice able thing if you do it on insulating layer
- If we go for etching of silicon dioxide on silicon nitride then there is no problem in hydrofluoric acid.
- If we want make this structure on silicon, then we have to go for buffer hydrofluoric acid because BHF does not attract silicon. It will attract only silicon dioxide.

➢ Now etching away the oxide underneath the Polysilicon structure, we refer to Polysilicon and silicon dioxide as the structural and sacrificial materials respectively.

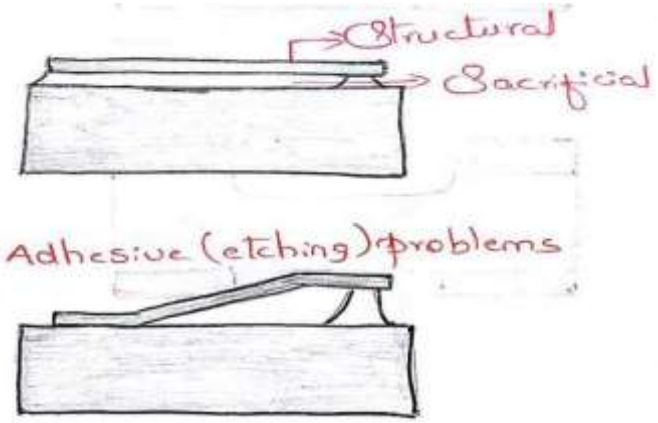
PROBLEMS IN SURFACE MICROMACHINING:

➢ One problem is surface stiction, the top layer is a structural layer and bottom on is a sacrificial.

➢ If it is small area we will stick that in surface of micromachining.

➢ Long beam will stick and as a result of which it may break where it is stick.

➢ That problem is known as surface stiction and the surface tension of the water under structures pulls them down to the surface of the wafer and causes them to adhere permanently to the wafer surface.



DIFFERENCES BETWEEN BULK AND SURFACE MICROMACHINING:

Bulk Micromachining		Surface Micromachining	
Advantages	Disadvantages	Advantages	Disadvantages
Well established technology since 1960		Uses several materials and allows for new applications	Relatively new since 1980
Rugged structure, withstand vibration and shock by micromachine structure	Large dry area that gives it high cost	Small die area that makes it cheaper	Less rugged with respect to shock and vibration,
Large Mass/Area	Not fully integrated with IC process is large mass and area you can use	Fits well within IC process	Small mass/ area reduces sensitivity
Well characterized material silicon(Si)	Limited structural geometry possible	Wider range of structural geometry in surface micromachining	Some of the materials are not well understood

QUARTZ MICROMACHINING:

- Quartz in a unique semiconductor material for microelectronics VLSI, MEMS and integrated sensors.
- It is basically quartz is a silicon dioxide insulator crystal because this is silicon dioxide but in crystallographic form.
- Silicon oxide quartz is crystallographic form. But normally silicon dioxide which is used for masking that is amorphous in nature.
- But quartz is a crystal material, it will have piezoelectric property, low temperature coefficient, high mechanical strength, thermal stability is very high.
- It is radiation hard unique oscillator for crystal.

QUARTZ MICROMACHINED STRUCTURES:

- We make cantilever beams, miniature tuning forks, triple beams, dual and double ended tuning forks, membranes and flexures. These kinds of structures have lot of application in quartz MEMS or MOEMS.

APPLICATIONS:

- One is oscillator structure. By using piezoelectric material we can get very good crystal oscillator and for that if we want to safe, it can be done by micromachining and the resonance frequency depend on the structure of the piezoelectric material.
- Accelerometer, Gyros can be made out of quartz, actuators because it is a piezoelectric material. If we apply electric field, it can vibrate with certain frequency.
- Vibrating motors, Optical choppers
- Temperature insensitive and radiation hard

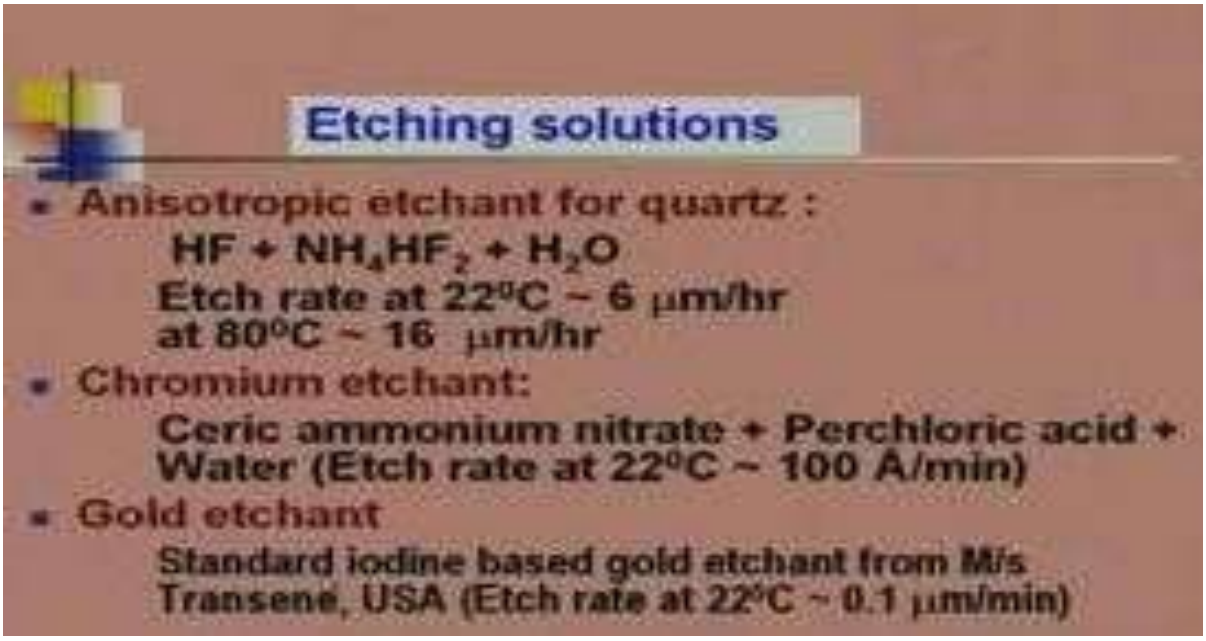
CHARACTERISTICS:

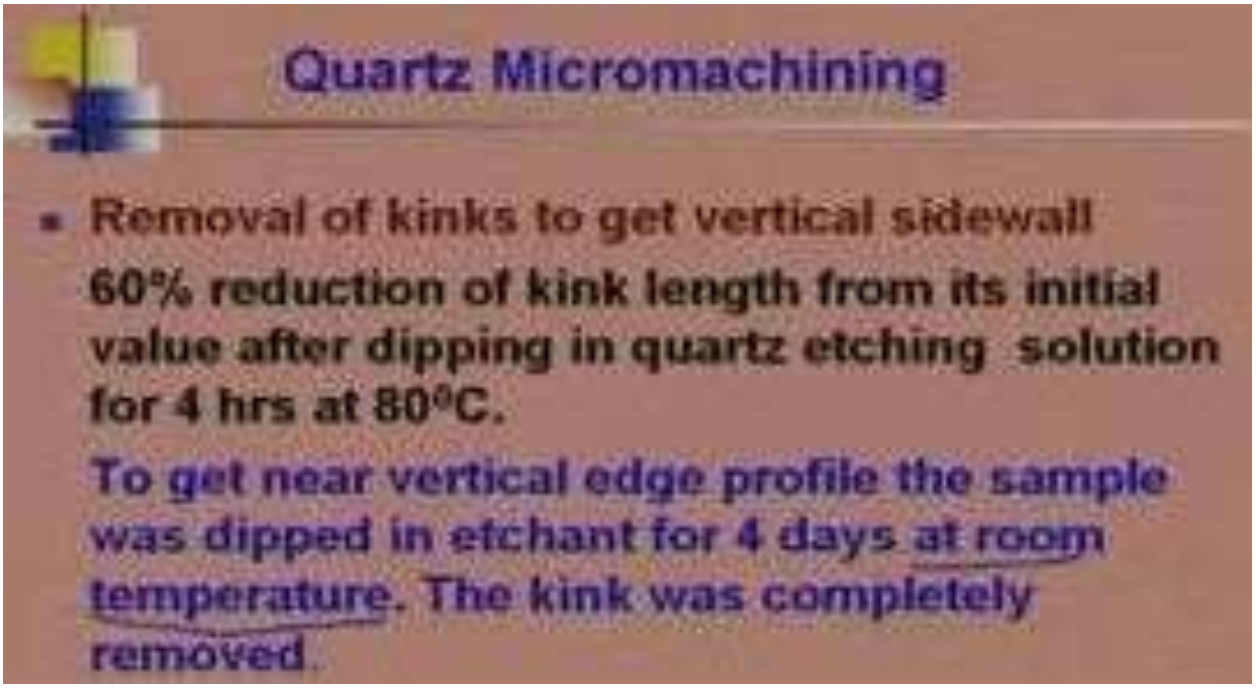
- Standardization of anisotropic etching of single crystal quartz.
- Etch standardize you have to do selection of proper masking material that can sustain prolonged etching in fluoride based solution. Because all etching solutions of quartz are fluoride based.
- Development and optimization of lithography process for micromachining of quartz which requires double side alignment.

- ➢ Development and optimization of selective deposition of electrode materials at the sidewall of quartz micromachine structures through vacuum masking technique.

ANISOTROPIC QUARTZ ETCHING:

- ➢ Chromium, gold is used as a masking material. 300 angstroms chromium film, 3000 angstroms gold film followed by patterning, it will get the masking material.
- ➢ Deep etching in HF based solution at various temperatures through chromium gold patterned mask.
- ➢ Hydrofluoric based solution is the etching solution. 80 percent hydrofluoric acid at 80 degree centigrade is the fast however large kinks crystallographic facets appear at both X and Y sections. So some crystallographic facets will be created and those facets will create some problem in your structure.
- ➢ Etching in saturated ammonium fluoride, HF^2 solution at 80 degree centigrade yields low etch rate and smaller kinks, so this part of the quartz etching.





FABRICATION OF MICROMACHINED MICROSTRUCTURE DEVICES

SILICON MICROVELCRO:

- Isotropic etching and anisotropic etching, both are used.
- Microvelcro is basically one application is button snap or zipper.
- Two microvelcro is in opposite way, there are joined together, that is your zipper.
- So a regular array of microstructure that can be used as a zipper in 2D configuration.
- The structures behave like the well-known Velcro material

PROCESS FLOW:

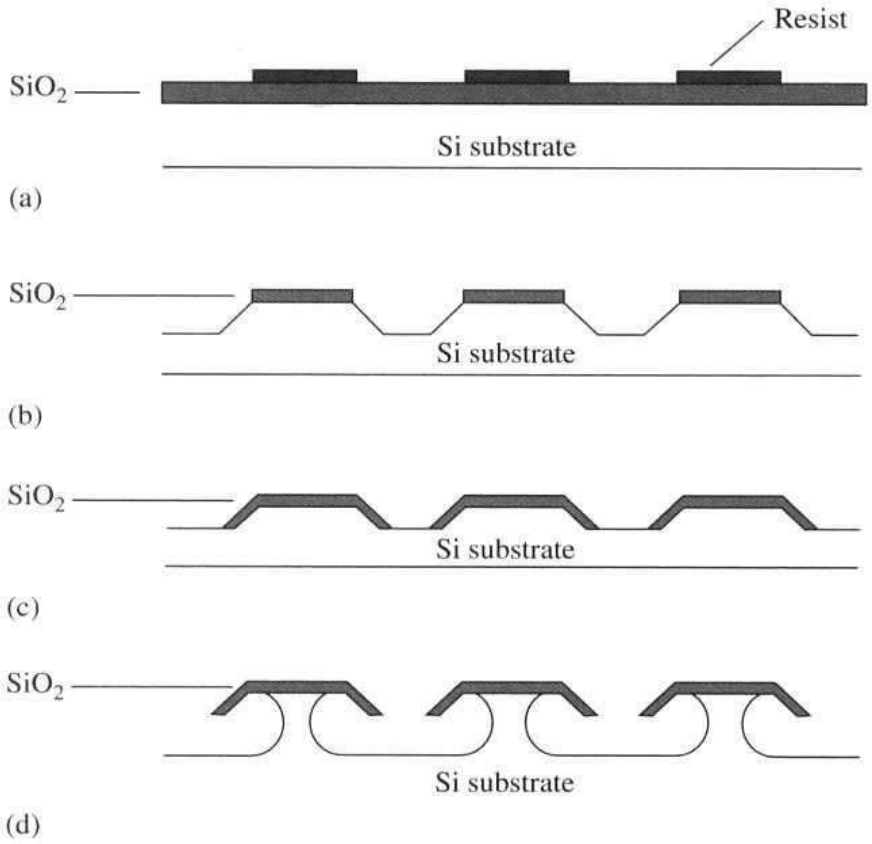
1. A 120-nm SiO_2 layer is grown at 1000°C in dry oxygen on (100) silicon wafers. The oxide is patterned using optical lithography into an array of 10 um2 rectangular islands, with one edge aligned 45° to the (110) flat

2. After photo resist stripping, the wafer is immersed in an anisotropic etch bath that consists of aqueous KOH (33-45 percent, 84 °C, 4 min) and isopropyl alcohol. The etching results in a truncated pyramid with exposed (212) planes, which are the fastest etching surfaces. The (212) planes intercept the (100) base plane at an angle of 48°

3. After stripping the masking oxide and cleaning the samples with a conventional chemical sequence, a thick SiO_2 layer (~1.0 to 1.5 um) is grown at 1000 °C in wet oxygen. The oxide is

patterned by a second mask that consists of an array of Greek crosses, each approximately 18-um wide, aligned to the original array.

4. The oxide crosses act as a mask for a second etch in KOH (~3 min), which removes some of the underlying silicon. Finally, the microstructures are completed by etching the wafer for two minutes in an isotropic etching bath (15:5:1 HNO3:CH3CO2H:HF). This step provides the vertical clearance for the interlocking mating structures and the lateral undercut necessary to produce the four overhanging arms.



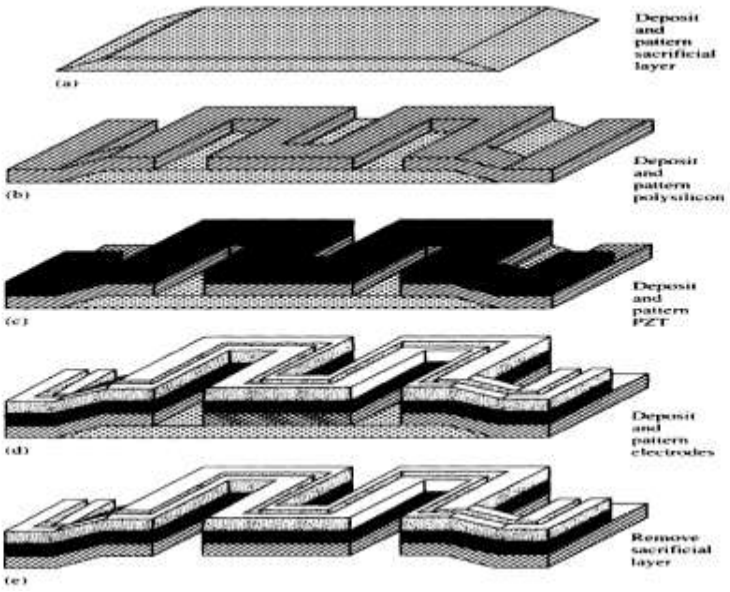
LINEAR MOTION ACTUATOR:

- So sensor can sense and actuator can act something that we have seen. So that means some kind of the attraction or some kind of repulsion kind of thing in a microstructure.
- So here is an example of the microactuator which is made out of the piezoelectric thin film, which is zinc oxide or PZT. The actuator uses folded path geometry
- When a voltage is applied to the dual electrodes, on the top surface of the piezoelectric thin film of PZT, the PZT either expands or contracts it length depending on the polarity of its voltage with respect to poly silicon layer.

- If the PZT or zinc oxide, the piezoelectric material if you apply some voltage with respect to a ground plane.
- So because of the inherent nature of the material there will be some contraction.
- So if the film tries to contract, the whole thing can be stretched.
- Because it is a folded structure or it can be either stretched or it can be compressed. So both are possible.
- The bottom is the poly silicon layer, the poly silicon ground plane, Now if you apply with respect to the poly silicon ground plane, positive voltage is here and here negative.
- So depending on positive and negative you can change for actuation either contraction mode or is a repulsion mode you can make it.

PROCESS FLOW:

1. The process starts with the deposition and patterning of the sacrificial material (SiO_2) .
2. This is followed by the deposition of a poly-Si layer as the structural layer. The poly-Si layer is then patterned.
3. The poly-Si deposition and patterning is followed by a deposition and patterning of PZT.
4. The fourth step is to deposit and pattern the metal electrodes , followed by an etch in HF solution to remove the sacrificial oxide and release the mechanical microstructure

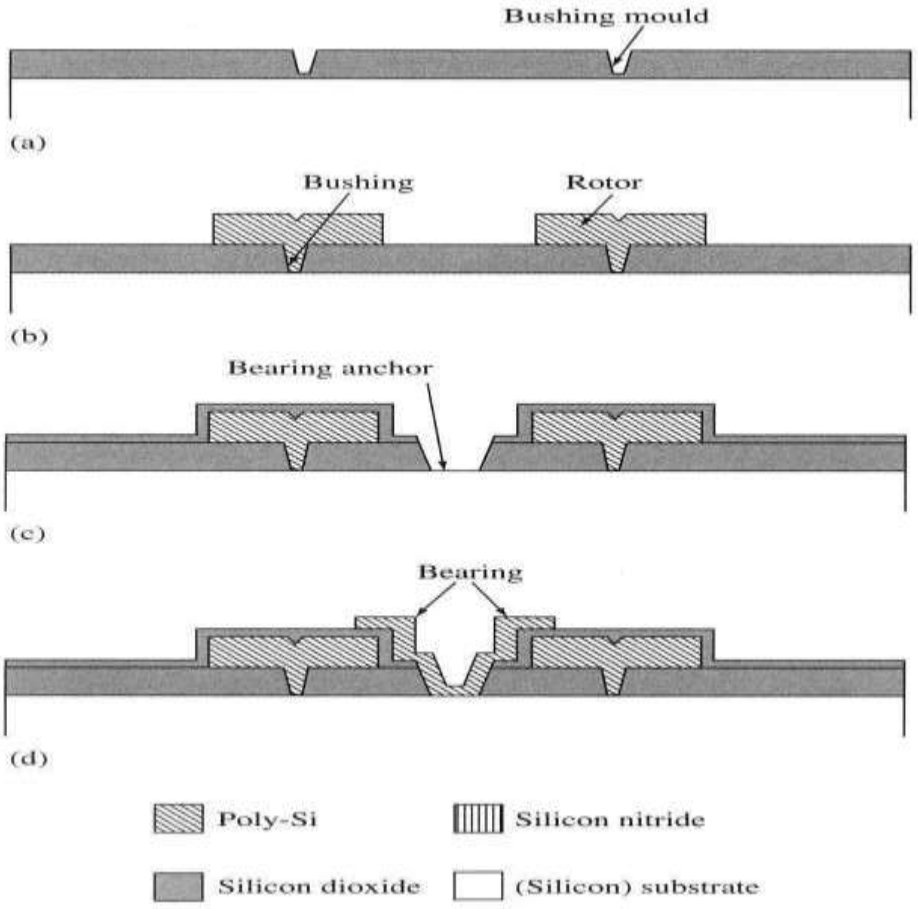


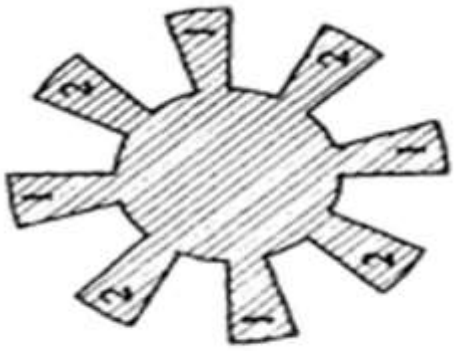
ROTOR ON A CENTER PIN BEARING:

- ➢ Rotor on a center pin bearing is another mechanical structure which may be made using the micromachining technology, rotor on a center pin bearing.
- ➢ So a center point bearing will be there a structure will rotate based on that bearing. That is used in many of the joints links.
- ➢ So there are lot of rotation motion is also required in many of the microactuators.
- ➢ Disc shape rotor made of poly silicon and that rotor is free to rotate about a poly silicon center bearing.

PROCESS FLOW:

1. The process starts with the deposition of an oxide layer as the first sacrificial layer on which the bushing moulds are patterned (Figure 6.8(a)).
2. Following the patterning of the first oxide layer, the first poly-Si structural layer is conformably deposited and patterned using the second mask as shown in Figure 6.8(b). The bushings are formed automatically on the deposition of the poly-Si layer. These bushings are often necessary to prevent stiction to the substrate when the structure undergoes the sacrificial oxide wet-etching process
3. Another oxide layer is deposited. This second oxide layer is also used as a sacrificial layer. The second and the first oxide layers are patterned using a third mask that carries the bearing anchor opening (Figure 6.8(c)). Note that at this stage of the process, the poly-Si rotor is totally encased within the two oxide layers.
4. The second poly-Si structural layer is then deposited and patterned using the fourth mask. This step defines the centre bearing as shown in Figure 6.8(d).
5. The rotor is finally released by etching the two sacrificial oxide layers in HF solution. A top view of the rotor structure is shown in Figure 6.9.





A top view of the rotor structure

MICROSTEREOLITHOGRAPHY

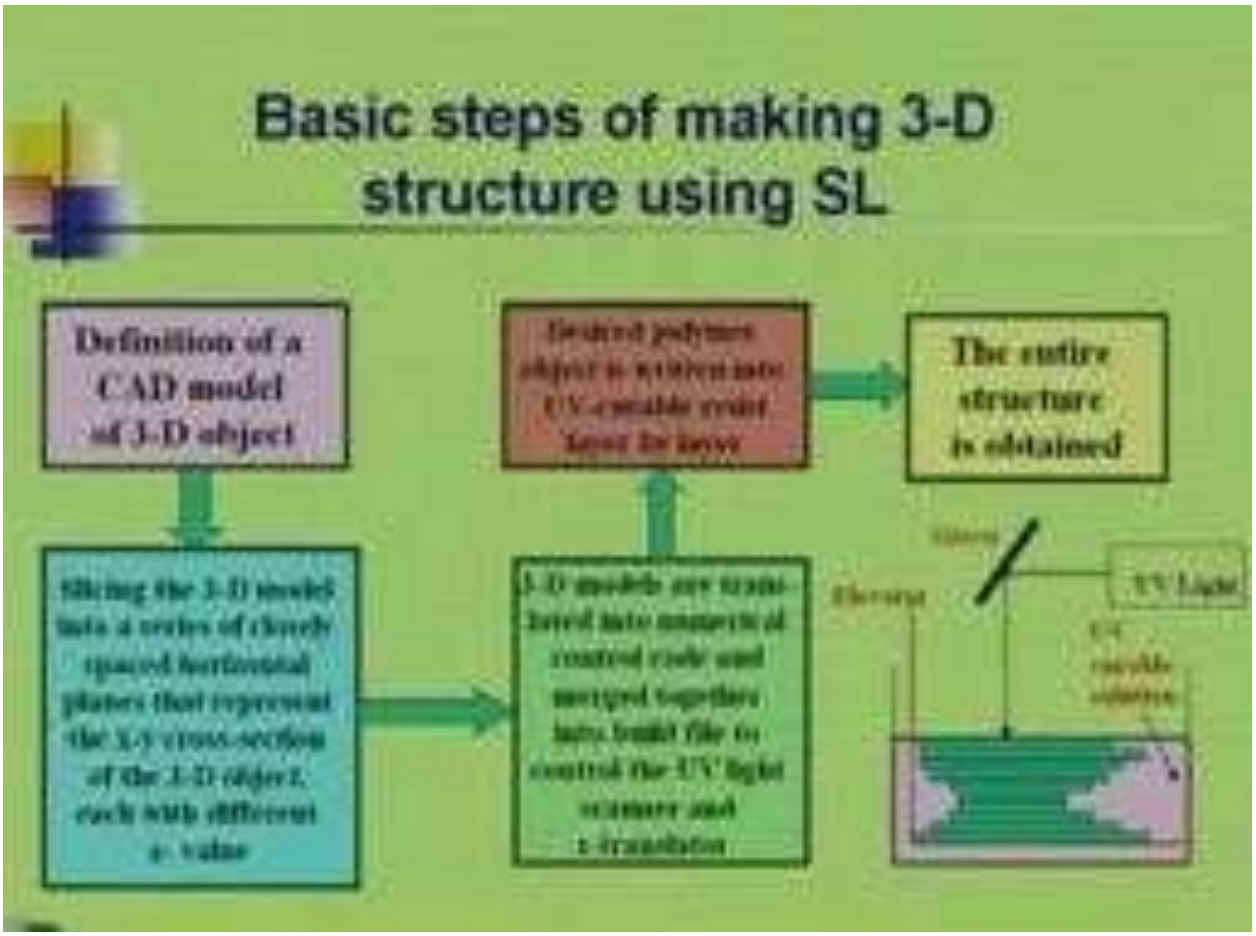
INTRODUCTION:

- Lithography means getting some structure from mask level on to the wafer level. But here we will not use any mask. This kind of structure fabrication is without using any mask.
- Nowadays not only out of silicon but also from other materials like polymer materials, ceramic materials, metals and composite materials and so on. The microstructures are fabricated separately using a certain technique and that particular technique is known as Microstereolithography.
- The name stereo is there, as the name stereo you understand that there it will be three dimensional structures.
- So normally the x, y and z in normal lithography or normal bulk and surface micromachining, there is a limitation on the thickness of the structure.
- Means along the z direction the thickness of the microstructure or materials, there is a limitation.
- But here in this particular technique which is known as Microstereolithography, there that limitation is not there.
- So you can have larger thickness material without any mask, without any micromachining by etching.
- Either etching or say etching may be liquid or liquid etching or may be plasma etching or dry etching. Those kinds of things we are not using here.

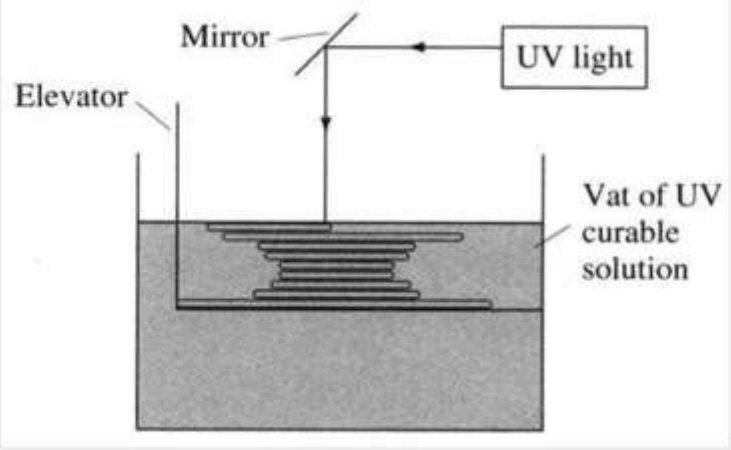
STEREOLITHOGRAPHY FOR MEMS:

- Stereolithography is defined as is a rapid prototyping and manufacturing technology that enables the generation of physical objects directly from CAD data file.
- So here one important point is a CAD data file and this CAD data file is different from the data file which is being used for making mask in case of the surface bulk micromachining or in case of VLSI process technology.

- Now this was first introduced by Japanese group in 1981 by Kodama and in Europe in 1984 by Andre and his group and in USA 1984 by Hull.
- Resolution in x-y movement the minimum movement of the feature as well as in the z direction the movement if you can make very small amount, then it is possible to make very small in a micro levels the parts layer by layer you can build.
- So that you can have very small sized micro parts or micro structures. That is a micro stereo lithography.
- Micro stereo lithography permits fabrication of true 3D devices on the micron to millimeter scale including curvilinear and re-entrant microstructures that are difficult to make using conventional micromachining curvilinear



- The stereolithographic process begins with the definition of a CAD model of the desired object,
- Followed by a slicing of the three-dimensional (3-D) model into a series of closely spaced horizontal planes that represent the *x-y cross sections of the 3-D object,* each with a slightly different *z coordinate value.*
- *All the 3-D models are next translated* into numerical control code and merged together into a final build file to control the ultraviolet (UV) light scanner and z-axis translator.
- The desired polymer object is then 'written' into the UV-curable resist, layer by layer, until the entire structure has been defined



Basic principle of stereolithographic: the writing of 3-D patterns into a series of layers of UV-curable resist at different heights

BASIC PRINCIPLE OF STEREOLITHOGRAPHY (SL):

- SL is a photopolymerisation process, that is, a process that joins together a number of small molecules (monomers) in a resin or resist to make larger molecules (polymers), which usually use UV radiation to polymerise (or cure) the resist material.
- A polymer material when reacts under exposure and the polymer chain is formed or the polymer structure is modified, then this method is known as the photopolymerization.
- Three main photopolymer systems used in stereo lithography are acrylate, epoxy resin and vinyl ether.

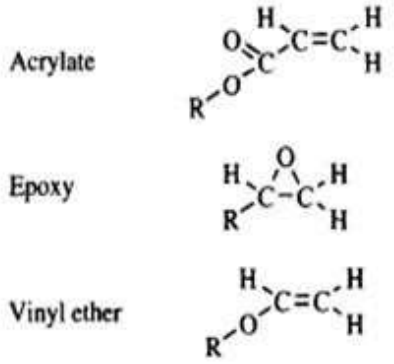
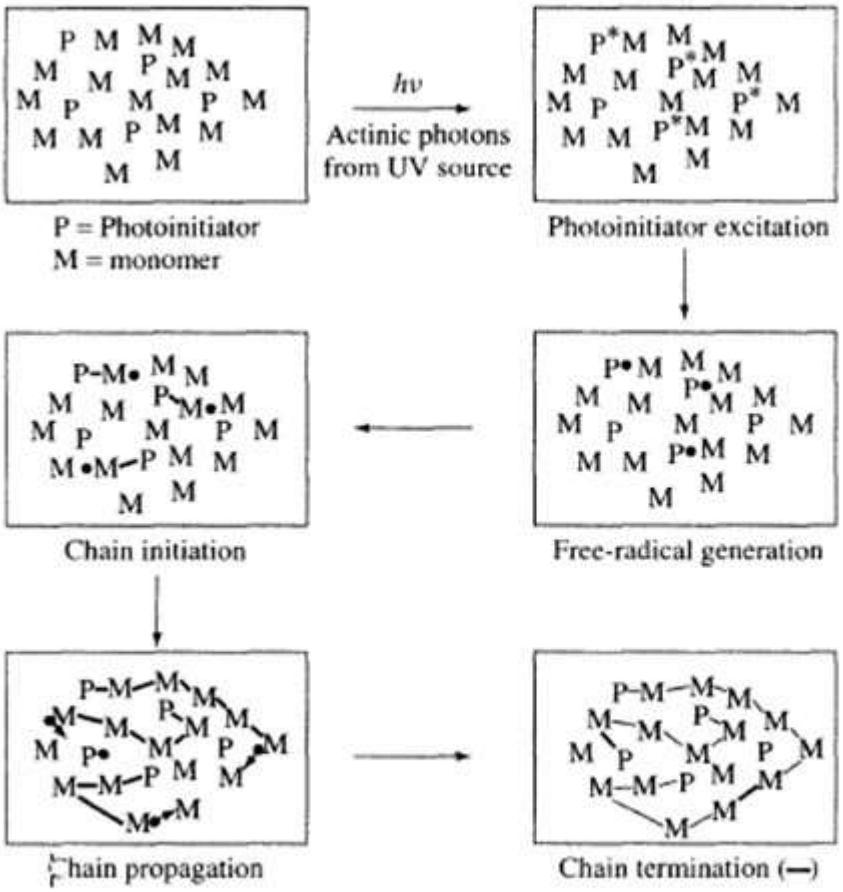


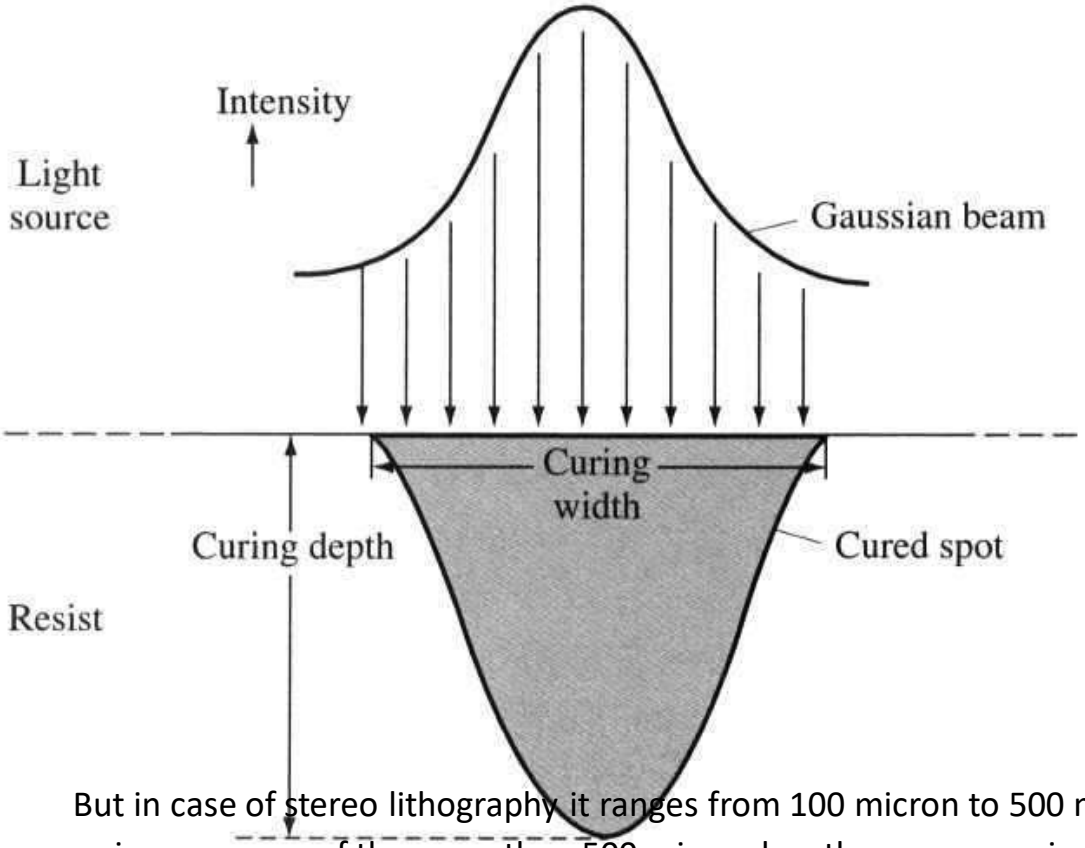
Figure Generalised molecular structure of three polymers used in MSL: acrylate, epoxy, and vinyl ether. From Jacobs (1996)

- Different types of photopolymers are used in SL prototyping and these are commonly based on either free-radical photopolymerisation or cationic photopolymerisation.
- In general, the photopolymerisation process is initiated by the incidence of photons generated by an UV light source.
- The breaking of the C—C double bond (acrylate and vinyl ether) or ring (epoxy) in the monomer enables monomer units to link up and form a chainlike structure.
- The cross-linked polymer chain finally forms when the chain propagation is terminated.



Example of a simplified free-radical photopolymerisation sequence used in MSL

- The curing depth and line-width of the photopolymerisation process are the two most critical parameters and these need to be carefully controlled in the SL process.
- In principle, the curing depth and line-width can be determined from the beam distribution and the absorption of radiation in the resist
- The curing depth we will tell you how much thick size thickness of polymer material it can polymerize. Because beyond that there is no intensity.
- So this curing depth and curing width in case of stereo lithography system and micro stereo lithography system are different.
- In Microstereolithography system obviously the curing width and curing depth will be much smaller in the range of shape few microns.



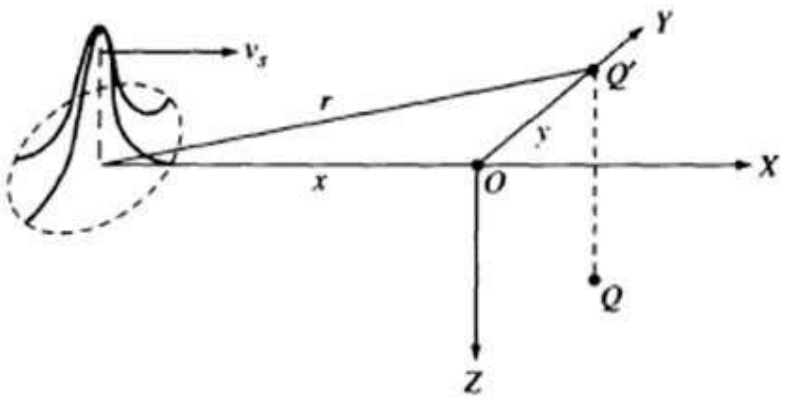
But in case of stereo lithography it ranges from 100 micron to 500 micron or in some case of the more than 500 micron length you can, curing width you can get it.

Fig: Theoretical intensity profile of the UV beam (Gaussian) and the resultant spot cured within the photo resist

- The fraction of light transmitted through an absorbing system is given by the Beer-Lambert law (see for example, Wayne (1998)):

$$It/I0 = \exp(-\alpha Cd)$$

- where *It, and I0 are the transmitted and incident light intensities,*
- *C is the concentration of* the absorber,
- *d is the distance the light has passed into the absorber,*
- *and α is constant* proportional to the absorption coefficient of the absorbing material at the wavelength used



Mathematical representation of the line scan of a Gaussian beam. From jacobs (1992)

- In the SL process, we consider the UV beam to have a Gaussian profile, which is scanned in a straight line at constant velocity *vs along the x-axis, which is in the surface* of the photopolymer, as shown in Figure 7.5 (Jacobs 1992).

$$I(x, y, z) = I(x, y, 0) \exp(-z/d_p)$$

- The irradiance (radiant power per unit area*), I(x, y, z) at any point within the resin* can be related to the irradiance incident on the resin surface*, I (x ,y, 0) using the* Beer-Lambert law

where *dp is the penetration depth of the beam*

$$l_w = 2w_0\sqrt{C_d/2d_p}$$

- The relationship between the curing depth and line-width is finally obtained and is given by

STEREOLITHOGRAPHIC SYSTEM:

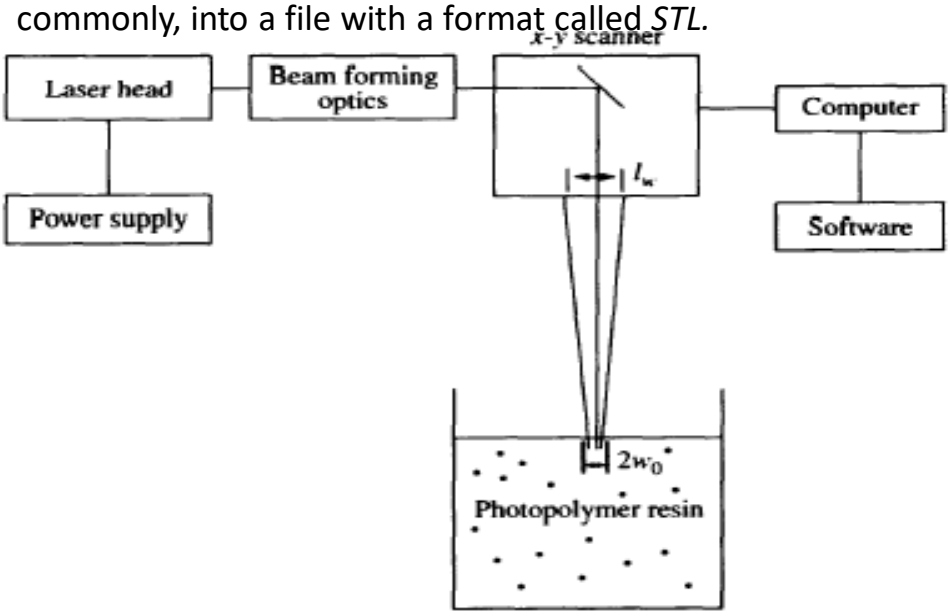
- All SL systems share the same basic elements or subsystems:

➢ The CAD design,

➢ Layer preparation functions, and

➢ A laser-scanning or imaging system.

- The CAD model is a 3-D representation of the object and is exported, most commonly, into a file with a format called *STL*.



Block diagram showing the basic elements of an SL system. From Jacobs (1992)

CAD DESIGN:

- ➢ CAD design means the data you have stored in files in different format so that the scanning will be done based on those data as well as the z axis movement will be there based on that data.
- ➢ That is the CAD design a file you have to create.

LAYER PREPARATION:

- ➢ The layer preparation is another very important and how you are preparing the layer, your intricacy of the device or all the whole method depends on how you are preparing the layer.
- ➢ The polymer layer, the photoresist layer and the CAD model in STL format
- ➢ It produces is a slice cross section converging parts are placed into a build file.
- ➢ That is the first CAD design first as subsystem.
- ➢ Process control software operates the stereo lithography writing process according to the build file.
- ➢ So writing will be done based on the build file which you have created and loaded into a computer.

- Flat resin layer of the desired thickness is prepared for curing. The liquid resins surface will be the foundation of each layer of the SL model.SL system should satisfy the following requirements of the resin surface.
- it should be uniformly flat, leveled and free from extraneous features.
- The resin layer must be at the focal plane of the imaging system. That means the focus spot where the beam focus beam is focused at a point the whole layer should be in that particular plane. So that there you will get maximum intensity.
- Surface must be a controlled distance above the previously build solidified cross section of the part.
- The recoating and leveling system work together to have a flat layer of liquid resin of proper thickness. Recoating and leveling. Because layer by layer you have to recoat.
- The thickness of the layer typically ranges 100 to 500 micrometer. Recoater must be controlled precisely to achieve thinner layers. As 25 micron Recoater error is significant for building layer below 100 microns.
- Any shrinkage during curing must be compensated by the excess resin the vat

IMAGING SYSTEM:

- Optic system basically
- It includes a light source that may be laser or ultraviolet source or we can use a UV lamp also.
- So that the light source must be appropriate for resin to be used, beam delivery and focusing element
- Wavelength output beam shape and power available are all important.
- Beam delivery elements are used to fold the path of the laser beam that compact the SL system.

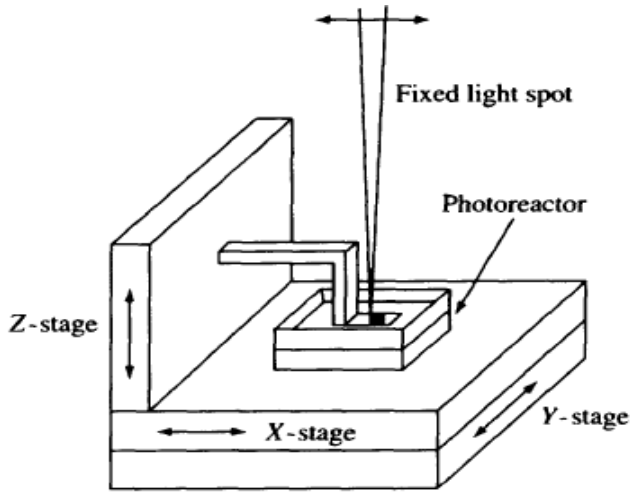
MICROSTEREOLITHOGRAPHY:

- MSL is also called *microphotoforming and was first introduced to fabricate high* aspect ratio and complex 3-D microstructure in 1993.
- The resolution of MSL is better than Stereolithography
- UV laser beam is focused down to a 1 to 2 micron-dia spot that solidifies a resin layer of 1 to 10 micron thickness.

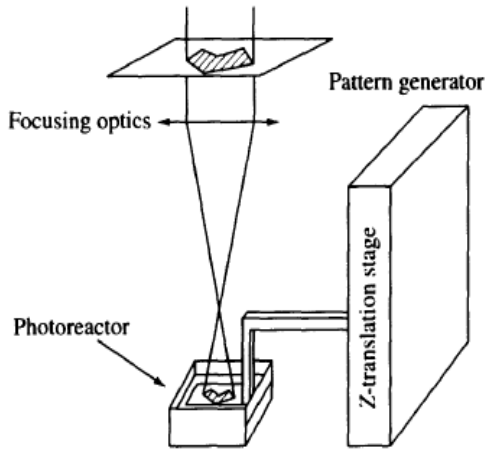
- Whereas in SL laser beam spot size and layer thickness are 100 to 1000 micrometer.
- Submicron control of both x-y-z translation stages and small UV beam spot enables precise fabrication of complex 3D microstructures.
- Microstereolithography is an additive process.
- In contrast to conventional subtractive micromachining and in principle compatible with silicon technology and therefore post-CMOS batch fabrication is feasible in some cases.
- Conventional micromachining is subtractive
- Different MSL systems have been developed in recent year to improve upon their precision and speed.
- Another research effort in MSL is the incorporation of a broad spectrum of materials.
- Polymer metal ceramic all these materials are being used in MSL technique to get microstructures.
- Most widely used MSL equipment are based on the scanning method where a well focused laser beam with beam spot size around 1 micron is directed onto the resin surface to initiate the polymerization process.
- They use recent MSL equipment. They use the laser beam of spot size nearly 1 micron.
- In microstereolithography a 3D microstructure is built up by repeated scanning of either the light beam or work piece layer by layer.
- Several scanning methods are used in MSL technique which are classical MSL integrated harden process which is known as IH process, mass IH process and super IH process.

SCANNING METHOD:

- Most MSL equipment developed today are based on the *scanning method* which is the method employed in conventional SL and is widely used in the industry. With the scanning method, a well-focussed laser beam with beam spot size around 1 micron is directed onto the resin surface to initiate the polymerisation process.
- A 3-D microstructure is built up by the repeated scanning of either the light beam or the work piece layer by layer.



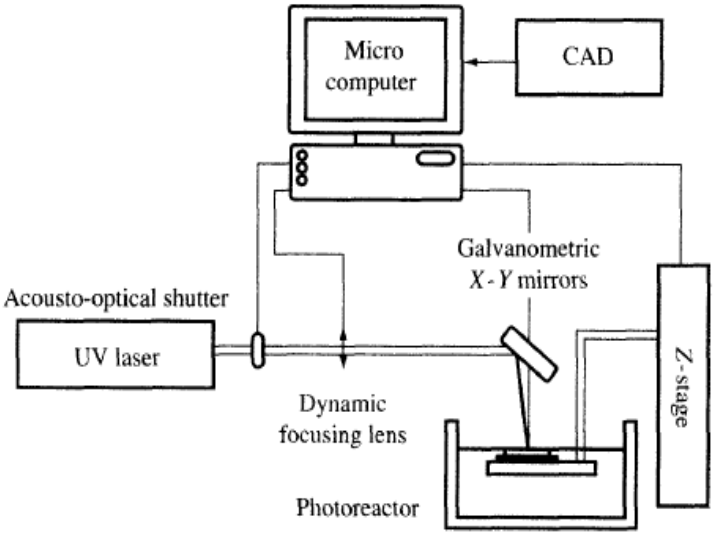
Principle of scanning MSL, that is, a vector-by-vector approach.



Principle of projection MSL, that is, a plane-by-plane approach.

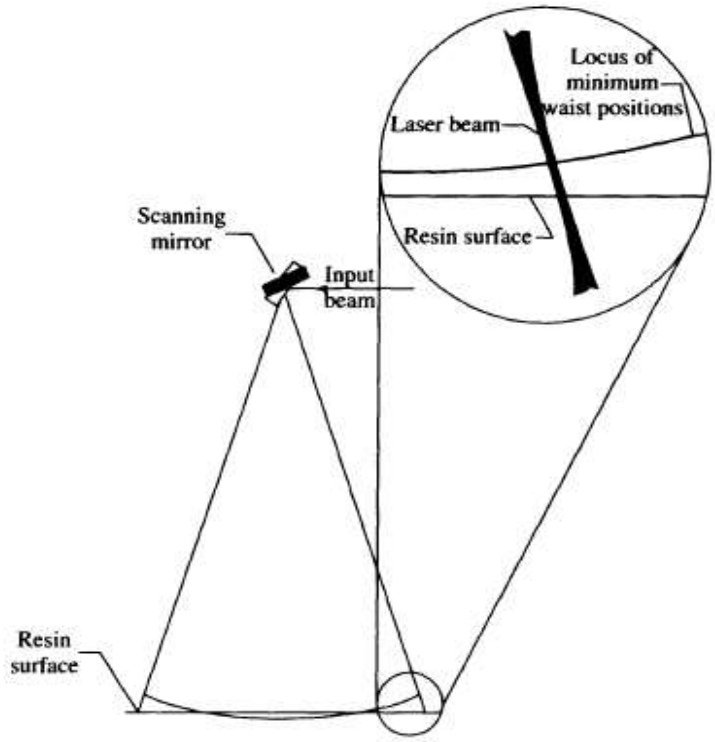
CLASSIC MSL:

- The classical setup for SL is shown in Figure , in which the laser beam is deflected by two low-inertia galvanometric *X-Y mirrors and is focused by a dynamic lens onto the* surface of the work piece in a photo reactor (vat) that contains a UV photo initiator
- *An acousto-optical shutter switches the laser beam on and off between* the polymerised segments.
- Small objects can be made with this type of apparatus, but improvements in the beam focus are necessary to obtain the higher resolution needed for microfabrication (less than 100 um).



LIMITATIONS IN CLASSIC MSL:

- ➢ It is believed that, in classical MSL, too many mobile optical elements lead to poor focusing.
- ➢ As shown in Figure, the free liquid resin surface defines a horizontal plane, whereas the motion of the focused laser spot describes a portion of the surface of a sphere.
- ➢ Thus, theoretically, the spot size varies during the scanning process. In classical SL, this defocusing may not be critical as a larger beam size (>100 um) and longer focal depth are used and an acceptable beam size and shape can be maintained across the flat resin surface
- ➢ Although this classical MSL system possesses some focusing problems that prevent high-resolution fabrications, it has a fast fabrication speed.
- ➢ Therefore, classical MSL is still an attractive option, as fabrication speed is always the first consideration of production.



Spherical beam swept over a flat resin plane in classical SL. From Jacobs (1996)

INTEGRATED HARDEN (IH) PROCESS:

- A series of integrated harden (IH) polymer SL processes have been developed by Ikuta and these are based on the classical scanning MSL method.
- The IH processes are designed to overcome the beam-focusing problem present in a classical MSL system.
- The apparatus for an IH process is shown in Figure , where the light source is a UV lamp (Xenon lamp) and where the beam is focused onto the resin surface through a glass window.
- The focal point of the apparatus remains fixed during the fabrication and the work piece is in a container that is attached to an *X-Y stage, which provides the* scanning that was realized previously by the galvanometric mirrors.
- Using an *X-Y stage* to move the work piece rather than the galvanometric mirrors to deflect beam leads to a smaller focal spot and hence higher resolution.
- Now, there is no need for a dynamic focus lens because the focal point is fixed.
- The glass window is attached to the Z-stage so that the layers of precise thickness can be prepared.

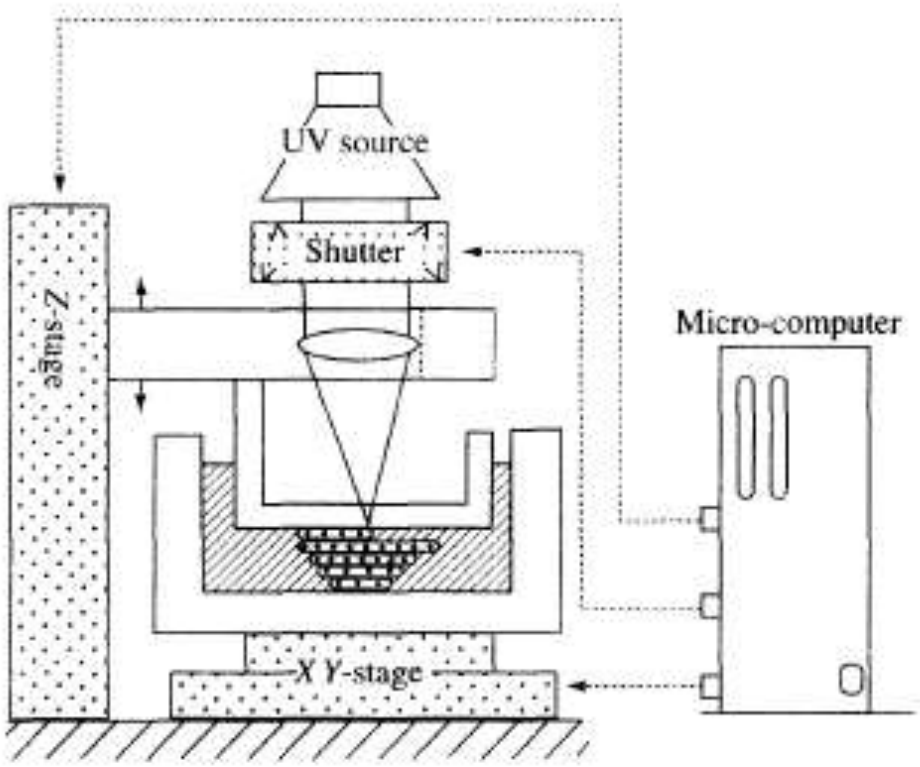
- The IH process can be used to fabricate polymeric microstructures, whereas metal microstructures can be obtained by first making a polymer micro mould, metal-plating, and finally removing the polymer

SPECIFICATIONS:

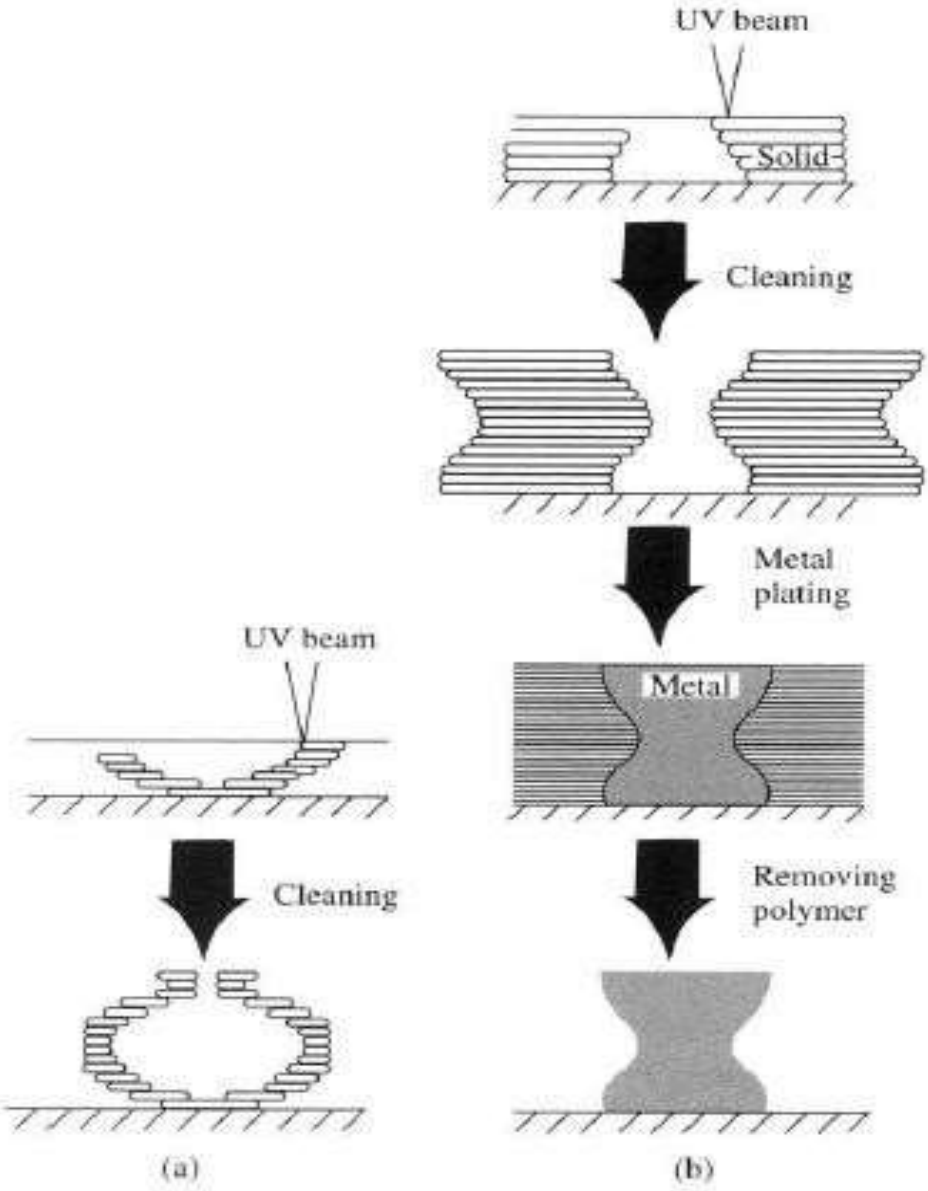
- 5 um spot size of the UV beam
- Positional accuracy is 0.25 urn (in the *x-y directions) and 1.0 um in the z-direction*
- Minimum size of the unit of harden polymer is 5 um x 5 um x 3 urn (in *x, y, z)*
- *Maximum size of fabrication structure is 10 mm x 10 mm x 10 mm*
- With this IH process, some high aspect ratio and truly 3-D polymer microstructures, such as micro pipes and micro springs .

CHARACTERISTICS:

- It is capable of making true 3-D and high aspect ratio microstructures
- It works with different materials
- It requires no mask plates and is thus a cost-effective process
- It has a medium range of accuracy (3 to 5 urn)
- It permits desktop Microfabrication of parts
- It should be pointed out here that the fabrication speed of the IH process is slower than classic MSL because the scanning speed of the *X-Y stage and container is less than that* of the galvanometric scanner.



Schematic diagram of the apparatus used for an IH process.



Basic steps in the IH process used to make a metallic micropart.

MASS IH:

- The slow fabrication speed of the IH process is a concern, and so the so-called mass-IH process was proposed by Ikuta in 1996 to demonstrate the possibility of realizing the mass production of 3-D microfabrications by MSL.
- The mass-IH process is schematically shown in figure and utilizes fibre-optic multibeam scanning. The basic idea is that an array of single-mode optical fibres can be used to enhance the speed of device production

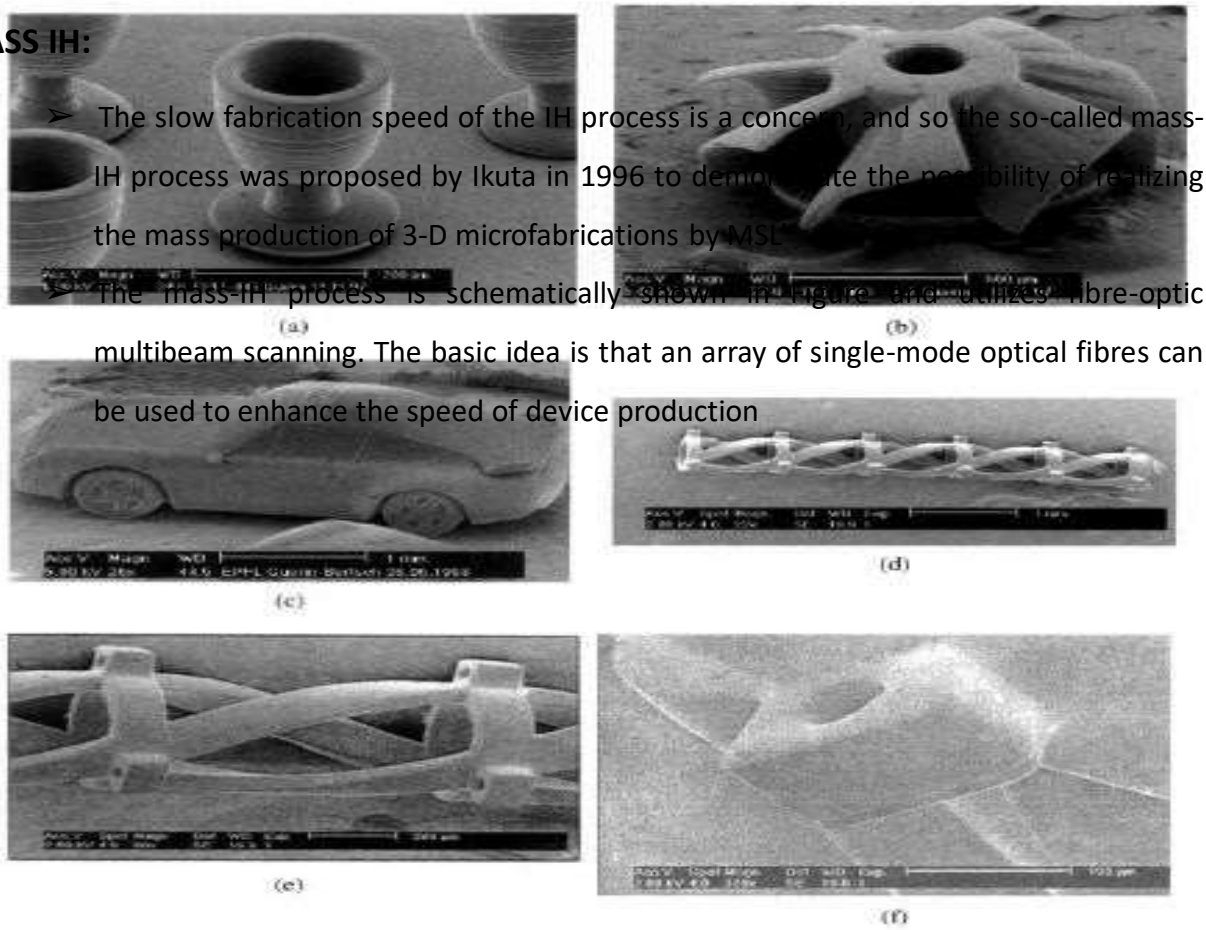


Figure 7.33 Complex 3-D microstructures fabricated using dynamic mask projection MSL: (a) microcup made up of 80 layers of 5 μm thickness; (b) microturbine made of 110 layers of 4.5 μm thickness; (c) microcars made of 673 layers of 5 μm thickness; (d) microsprings made of 1000 layers of 5 μm thickness; (e) close-up of spring; (f) lateral hole in the structure made of imbricated spring; (g) a side mirror of a car made of about 20 layers; (h) wheel of a car; (i) detail of car microprints on the roof of the car; (j) double-end connector made of 700 layers of 5 μm thickness; (k) two channels corresponding to each tube connector with external diameter of 200 μm. From Beluze *et al.* (1998, 1999)

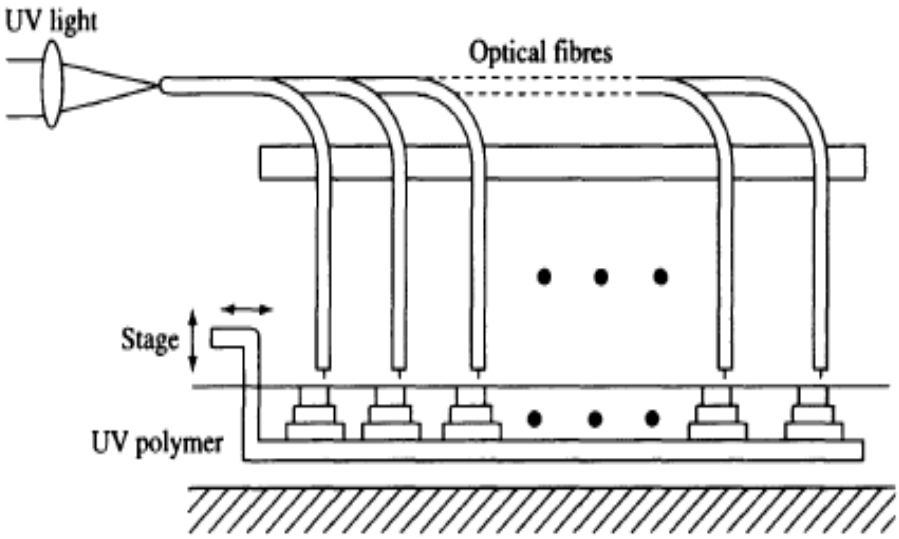


FIG: The mass-IH process designed to increase the speed of MSL through the use of an array of optical fibres. From Ikuta *et al*. (1996)

SUPER IH PROCESS:

- Both the IH and mass-IH processes are based on a scanning method with layer preparation, which shares the same basic principle as conventional SL.
- Two of the problems associated with this kind of layer-by-layer fabrication are as follows:
  - The depth resolution is limited by the thickness of the layer that is stacked up
  - Viscous UV-curable monomers can deform and hence damage the solidified microstructures
- Super IH process solidifies the monomer at a specific point in 3D space by focusing a laser beam into a liquid UV curable monomer.
- In super IH process is not layer by layer.
- The complete monomer complete the polymer resists as kept in a container.
- Then focused beam is scanned and focused beam the whole structure moves vertically also.
- But it will just reaction will take place at a particular point where the beam is focused inside the liquid.
- So that means if the focused spot of the optics either laser or UV is moved, is scanned inside the liquid at a different distance at difference depth.
- In the super IH process you do not need the support layer. Because the whole liquid is taken in a container.

➢ The beam spot in a 3D movement you are just focusing inside the liquid and now you are hardening the particular spots and after that you are curing and you are getting the structure.

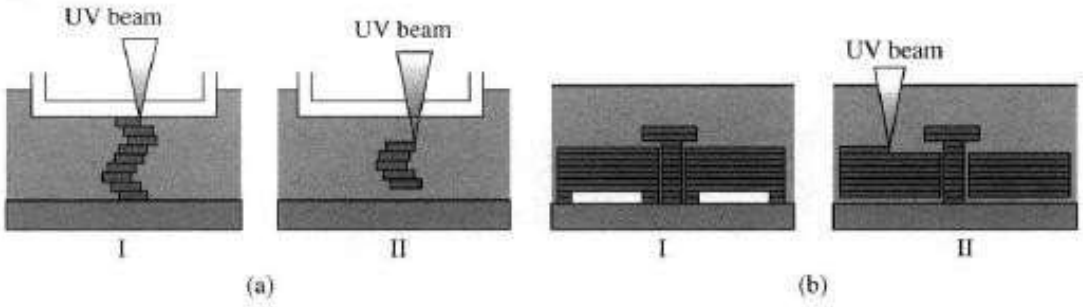


Figure (a) Comparison of the solidification processes of conventional MSL (I) and the new super-IH process (II) and (b) processes needed to make movable gear and shaft (I). Conventional MSL needs support structure, whereas the new super-IH process (II) does not need a support

CERAMIC MSL:

- ➢ So ceramic materials have useful properties such as high temperature or chemical resistance, high hardness, low thermal conductivity, ferroelectricity and piezoelectricity.
- ➢ Because of those properties, ceramic materials are used in some MEMS devices.
- ➢ 3D ceramic microstructures are of special interest in applications such as micro engines and microfluidics.
- ➢ These are the two application areas of ceramic microstructures. Unlike conventional silicon micromachining, MSL can be used to build the complex ceramic 3D microstructures in a rapid free form fashion without the need for high pressures and high temperature.