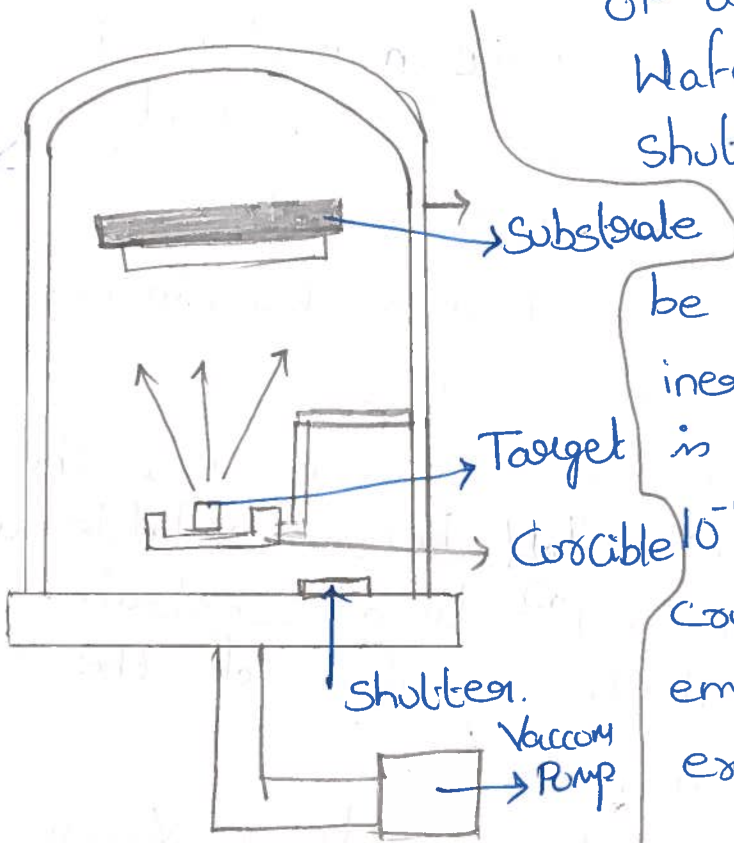
Microelectronic Technology for MEMS:

Evaporation:-

Thin Metal films Can be evaporated from a hot Source onto a Substrate.

An evaporation system Consists of a Vaccum chamber, Pump, Wafer holder, Crucible and a shutter.



A Sample of the metal to be deposited is placed in an inert crucible and the chamber is evacuated to a pressure 10^{-6} to 10^{-7} torr.

Crucible is heated by means of embedded heater and an external power supply.

Crucible is then heated using tungsten filament or an electron beam to flash-evaporate the metal from the crucible and Condense onto the Cold Sample.

The film thickness is determined by the length of time that the shutter is opened and Can be measured using a QMB-based film thickness monitor.

Metals that have low melting point Tmp are easily evaporated, Where as refractory metals require high temperature and Can Cause damage to polymeric or plastic Samples

→ Evaporated films are highly disordered and have large residual stresses thus only thin layers of metal can be evaporated.

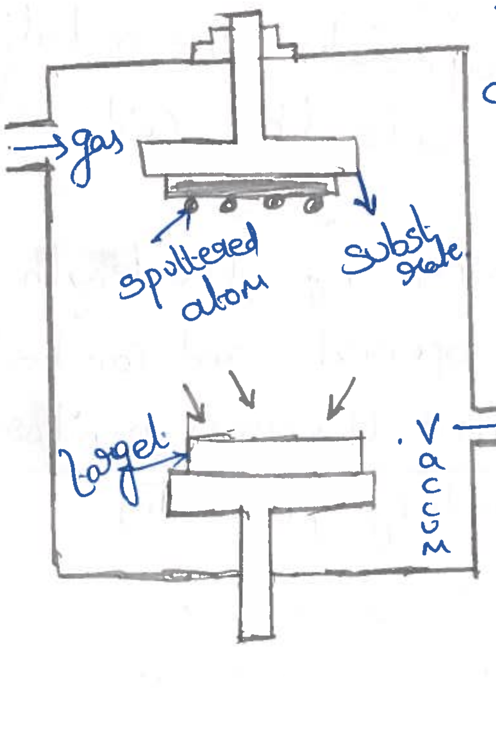
The deposition process is relatively slow at a few nanometers per second.

Sputtering:-

→ It is a physical phenomenon involving the acceleration of ions via a potential gradient and the bombardment of a 'target' or cathode.

→ Sputtering was developed as a thin film deposition technique by Langmuir in 1920.

→ Through momentum transfer atoms near the surface of the target metal become volatile and are transported as a vapor to a substrate. A film grows at the surface of the substrate via deposition.



Sputtering system consists of vaccum chamber, a sputtering target of the desired film, a sample holder and a high voltage dc or radio frequency (RF) power supply.

Evacuating the chamber down to a pressure 10^{-6} to 10^{-8} Torr an inert gas such as helium is introduced into the chamber down at a pressure of few mTorr.

→ A plasma of inert gas is then ignited. The energy of the bombarding ions is suffecient to make some of the target atoms escape from the surface.

Some of these atoms land on the Sample surface and form a thin film.

Sputtered films tend to have better uniformity than evaporation ones as sputtering over comes the temperature limitations of Evaporation.

Most of the elements from periodic table can be sputtered as well as inorganic and organic Compounds.

Refractory materials can be sputtered with ease, where as evaporation of materials with very high boiling points is problematic.

Also materials from more than one target can be sputtered at the Same time. (co-sputtering).

The structure of sputtered films is mainly amorphous and its stress and mechanical properties are sensitive to certain specific sputtering Conditions.

Some atoms of inert gas can be trapped in the film causing anomalies in its mechanical and structural characteristics.

Oxidation:-

High quality amorphous silicon dioxide is obtained by oxidizing silicon in either dry oxygen or in steam at elevated temperatures (850-1,150°c).

Thermal oxidation of silicon generates Compressive stress in the silicon dioxide film.

two Reasons of stress:-

~~Sid~~ Silicon dioxide molecules take more volume than silicon atoms and there is a mismatch between Coefficients of thermal expansion of silicon and silicon dioxide.

The Compressive stress depends on the total thickness of the silicon dioxide layer and Can reach hundreds of MPa.

Thermally grown oxide films Cause bowing of the underlying substrate.

Thermally grown silicon oxide tend to wrap or Curl due to stress variation through the thickness of the film.

Freestanding membranes and suspended Cantilevers are made of thermally grown silicon.

Thermal Oxidation:-

$Si + O_2 \rightarrow SiO_2$ (Dry)

$Si + 2(HO) \rightarrow SiO_2 + H_2\uparrow$

$Si + 2H_2O \rightarrow SiO_2 + 2H_2(\uparrow)$ (Wet)

Chemical Vapor Deposition:- (CVD)

CVD is defined as the formation of a non-Volatile solid film as a substrate by the reaction of Vapor phase chemicals that Contain required Constituents.

Applications:-

Polysilicon film deposition

Dielectric film deposition (SiO_2, Si_3N_4)

Single Crystal epitaxial growth

Metal film deposition.

Mechanism:-

→ Transfer of reacting gases to the substrate.

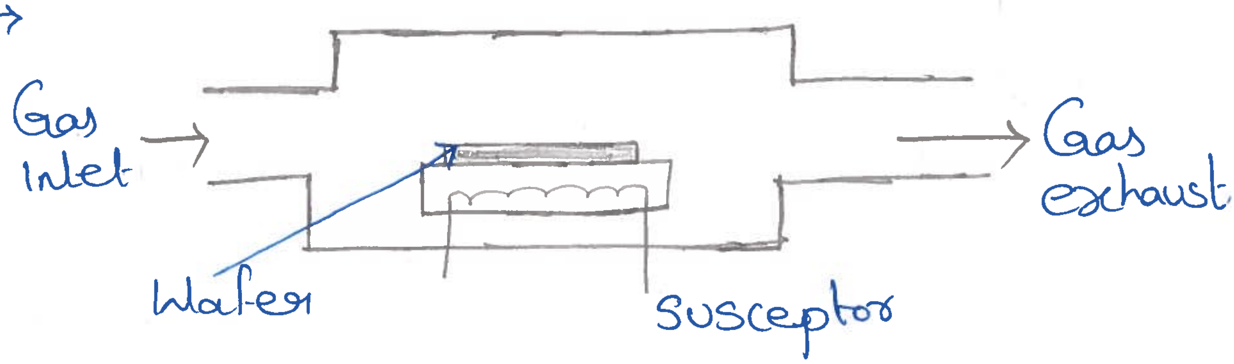
→ Absorption of species on the substrate surface.

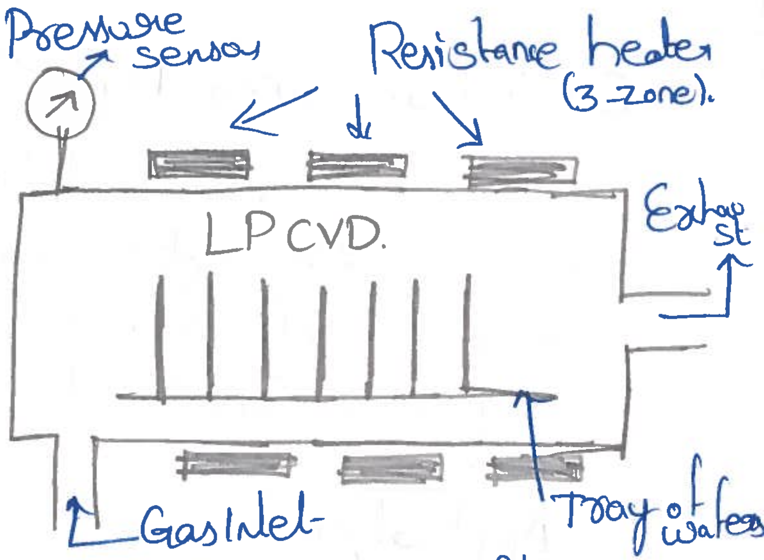
→ Heterogenous surface reaction Catalyzed by the Substrate surface.

→ Desorption of gaseous reaction by products.

→ Transportation of reaction by products away from the substrate.

→





A CVD reactor system will have a gas inlet, A Susceptor on which the wafers are kept and Susceptors are heated. if you heat the susceptor the gas will flow on to the surface of the wafer.

In this reaction ~~the~~ at high temperature. the gas will decompose and the solid material will deposit on the substrate.

Ex :- Silane gas SiH_4 to form polysilicon.

$$SiH_4(g) \longrightarrow SiH_2(g) + H_2(g) = \text{high temperature}$$

$$SiH_2(g) \longrightarrow SiH_2(a)$$

↳ absorbed species

$$SiH_2(a) \longrightarrow Si(solid) + H_2(g).$$

Low pressure CVD :- (LP CVD)

This technique permits either horizontal or vertical loading of the wafers into the furnace for processing. and accomodate large no. of wafers with ~~uniformal~~

It gives good conformal-step coverage excellent purity and uniformity.

There is less dependence of the resulting layer on gas flow. Process requires high temperature and deposition rate is low.

Ion Implantation:-

→ Used for atomic and Nuclear Research
→ Early idea introduced in 1950's
→ Introduced in semi conductor manufacturing in mid -1970's.

Two Problems associated with diffusion especially for IC fabrication – high- ~~depth~~ temperature process
– stress.

Ion Implantion is a relatively simple means to Place a known number of atoms in a wafer.

Process:-

→ Ionization of dopant source to form positive ions.
→ Acceleration of ions through a high voltage field to reach the required energy.
→ Projection of high-energy ions towards the wafer- surface.
– Collision of ions and silicon atoms resulting in energy loss
– End of penetration of ions in the substrate (coming to rest).

Silicon Dopants P-type:-

Boron.
Aluminium
Nitrogen
Gallium
Indium.

Silicon N-type:- Bismuth
Lithium
Arsenic
Phosphorus.

Ionization:- Process by which an atom or molecule acquires a negative or positive charge by gaining or losing electrons to form ions.

Major Components:-

→ Ion Source (gases AsH_3, PH_3, B_2H_6)

→ Mass Spectrometer (excellent ion purity Control)

→ HV Accelerator (voltage upto 1 MeV)

– Scanning System (X-Y deflection plates for electronic Control

– Target chamber (Vaccum).

Lithography:-

Lithography Sometimes is called a photo lithography.

→ It is a process that is used for device fabrication a system that transfer specific patterns from Photomask or rectile to the surface of a substrate.

→ Photoresist is an organic polymer which becomes Soluble / insoluble when exposed to UV light. It contains a light sensitive ~~substance~~ substance. Whose properties allow image transfer onto a Wafer.

→ Depending on the polymer used, either exposed or non exposed area of the film is removed in the developing process.

→ In photolithography a photo sensitive polymer film is applied on silicon Wafer.

This photosensitive polymer is known as Photo Resist.

Photo Resist is of 2 types:-

Positive PR:-

After exposure to proper light energy, Polymers are converted into a more soluble state.

High Resolution than Negative PR.

The unexposed region donot swell much

Negative PR:-

After exposure to proper light energy, the polymers are converted into a less soluble state.

→ cheap
→ Limited Resolution.

The film is dried and exposed with the proper geometrical patterns through a photo mask to UV light or other radiation.

exposed to UV light → UV lithography.
X-ray → X-ray lithography.
ion/electron beam → ion/electron beam lithography.

→ Resists are designed to react with UV/X-ray/e-Beam

→ lithography Requires. spinner, Resists, mask, mask aligner, developer solution, baking, ovens, etc.

Cleaning:-

If organic or inorganic Contaminations are present on the wafer surface they are usually removed by wet chemical treatment

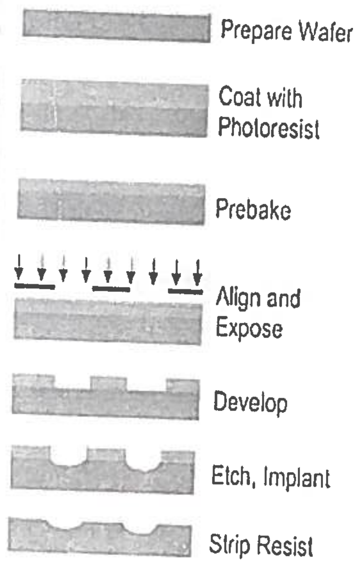
e.g RCA clean (Hydrogen peroxide solution).

Preparation:-

The wafer is initially heated to a temperature to drive off any moisture that may be present on the wafer surface. 150°c for ten minutes.

Wafers that have been in storage must be chemically cleaned to remove Contamination.

A liquid or gaseous "adhesion Promoter" such as Bisamine, "hexamethyl disilazane" HMDS is applied to promote adhesion of the photoresist to wafer.



The HMDS Can be applied by spinning a diluted Solution directly on wafer and allowing the HMDS to spin dry. If HMDS is not allowed to dry properly dramatic loss of adhesion will result.

This water repellent layer Prevents the aqueous developer.

from penetrating between the photoresist layer and the wafer's surface.

Photo Resist application:-

The wafer is covered with Photoresist by Spin Coating.

A viscous liquid solution of photoresist is dispensed onto the wafer and the wafer is spun rapidly to produce a uniformly thick layer. Spin Coating process results in a uniform thin layer uniformity within 5 to 10nm.

Spin Coating typically runs at 1200 to 4800RPM for 30 to 60 seconds.

The thickness depends on the viscosity of PR and the spin speed of the Coater.

Temperature Control of PR by water and of ambient and spindle by airflow.

→ The thickness is also determined by the evaporation of liquid solvents from the resist.

→ Non-Circular wafers greatly increases the Edge bead height.

→ EBR on front side and Back side

The Photo Resist-Coated wafer is then Prebaked to drive-off excess photoresist solvent typically at 90° to 100°C for 30 to 60 seconds on hot plate

Etching:-

In etching a liquid or plasma chemical agent removes the uppermost layer of the substrate in the areas that are not protected by photoresist.

In semiconductor fabrication dry etching techniques are generally used as they can be made anisotropic in order to avoid significant undercutting of the photoresist pattern.

Wet etch process are generally isotropic in nature.

Photo Resist Removal:-

→ After a photo Resist is no longer needed from the substrate. it must be removed. This usually requires liquid "resist stripper" which chemically alters the resist so that it is no longer adheres to the substrate.

→ Photoresist may be Removed by a plasma containing oxygen which oxidizes it. This process is known as ashing. When Resist has been disolved, the solvent can be Removed by heating to 80°C without leaving any residue.

Exposure and developing:-

After prebaking the photoresist is exposed to a pattern of intense light.

Exposure to light causes chemical change that allows some of the photoresist to be removed by a special solution called "developer".

Positive photo Resist: the common type becomes soluble in the developer when exposed.

Negative photoresist: unexposed regions are soluble in the developer.

A Post Exposure bake is performed before developing, typically to reduce standing wave phenomena caused by the destructive and constructive interference patterns.

In deep UV lithography chemically amplified Resist (CAR) chemistry is used.

The Resulting Wafer is then "hard baked" if a non-chemically amplified resist was used typically at 120 to 180°c for 20 to 30 minutes. The hard bake solidifies the remaining photo resist to make a more durable Protecting layer.

→ Lift off Technique is used to define a structured geometry on a substrate.

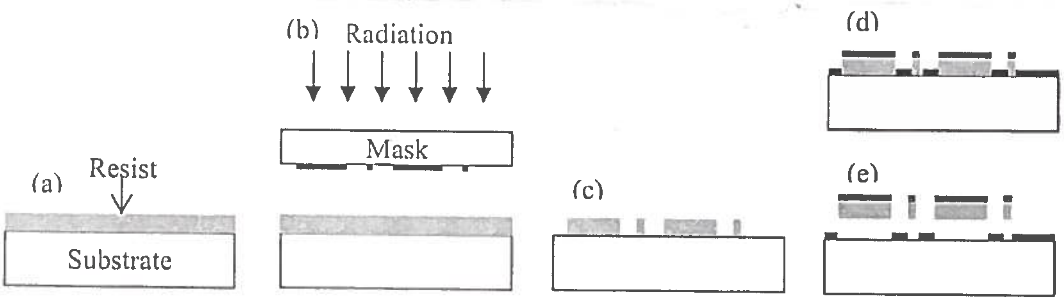
The process steps involved in this are are as shown in below.

The positive resist is spin coated and then exposed to the radiation.

A thin film of the desired metal or material is deposited on top of this structure.

The resist of the film is deposited in an appropriate solution, which detaches the film on top of the resist.

The Primary criteria for the lift off Process is to be effective that the thickness of the deposited thin film should be less than that of the resist.



The film ... developer which ... material ... deposited on ... the ...

The result of the film is ... depicted in an appropriate solution which determines the film on top of the result.

The ... ... of the deposited ... on the ... that of the result.

Micromachining:-

Micromachining usually refers to the fabrication of micromechanical structures with aid of etching technique to remove part of the substrate or a thin film.

Silicon has excellent mechanical properties

Micromachining is defined to be a process of shaping silicon or other material to realize 3-D mechanical structure in miniature form.

Etching:- It is a process by which patterns are transferred by selective removal of un-masked portions of layer.

Wet Etching:-

It is a material removal process that uses liquid chemicals or etchants to remove materials from a wafer.

Materials that are not protected by the masks are etched away by liquid chemicals. These masks are deposited and patterned on the wafers in a prior fabrication step using lithography.

The Wet etch process can be described by three steps

→ Diffusion of liquid etchant to the structure that is to be removed.

→ The reaction between the liquid etchant and the material being etched away.

→ A reduction - oxidation (redox) reaction usually occurs. This reaction entails the oxidation of the material then disolving the oxidized material.

Anisotropic Wet Etching :- (Pattern transfer with Perfect fedility)

Liquid etchants etch Crystalline materials at different rates depending upon which crystal face is exposed to the etchant.

There is a large difference in the etch rate depending on the silicon Crystalline plane.

Some of the anisotropic wet etching agents for silicon are :- KOH Potassium hydroxide.

EDP ethylenediamine pyrocatechol

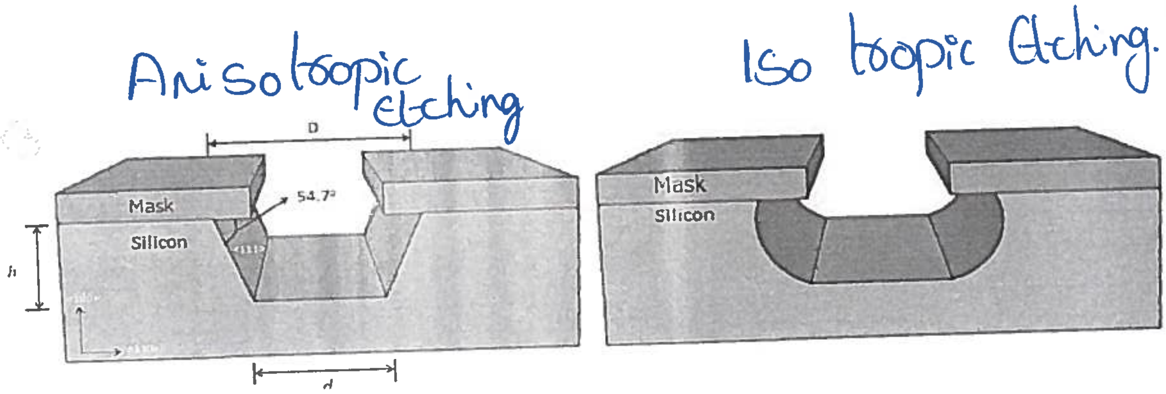
TMAH (Tetramethy ammonium hydroxide).

Etching a 100 silicon wafer we get a slant surface i.e 54.74° with the top surface.

100 silicon Etches faster than 111 silicon wafer.

The relationship between mask dimensions, etch depth and the floor width

$$d = D - \left(\frac{2h}{\tan(54.7^\circ)}\right).$$



Isotropic Wet Etching:-
(Etch rate is independent of direction)

Isotropic Wet etching the most common etchants are :- hydrofluoric acid
Nitric acid
acetic acid. (HNA)

The Concentration of etchants determines the etch rate.

Silicon dioxide or silicon nitride is usually used as a masking material against HNA.

As the reaction takes place the material is removed laterally at a rate similar to the speed of etching downward.

19 Wet chemical etching is generally isotropic even though a mask is present since the liquid etchant can penetrate underneath the mask. If directionality is very important for high resolution pattern transfer, wet chemical etching is normally not used.

Dry Etching:-

In dry etching plasmas or etchant gases remove the substrate material.

The reaction that takes place can be done utilizing high kinetic energy of particle beams, chemical reactions or a combination of both.

Plasma (Physical)
~~Physical~~ dry etching:-

It requires high kinetic energy beams to etch off the substrate atoms.

When high kinetic energy particles knock out the atoms from the substrate surface the material evaporates after leaving the substrate. There is no chemical reaction taking place and therefore only the material that is unmasked will be removed.

Plasma:- hot ionized gas consisting of approx equal numbers of positive charged and negatively charged electrons.

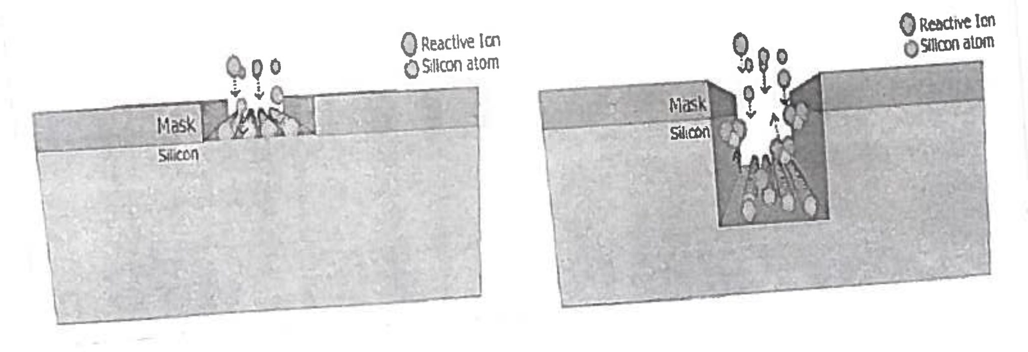
Chemical Dry Etching:-

This process does not use liquid chemicals or etchants. This process involves a chemical reaction between etchant gases to attack the silicon surface.

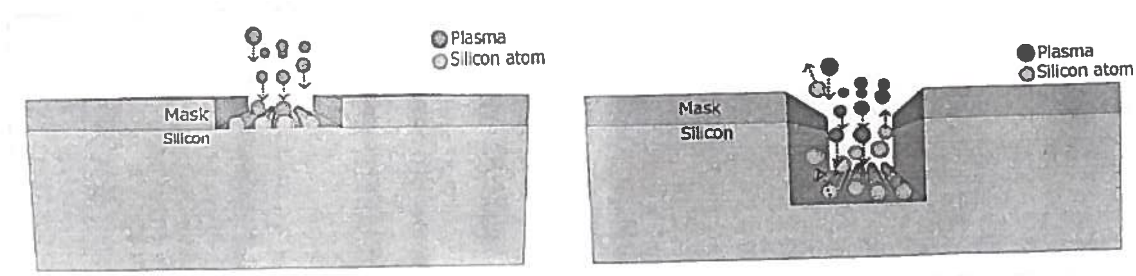
The chemical dry etching process is usually isotropic.

Anisotropic dry etching has the ability to etch with finer resolution and high aspect ratio than isotropic etching.

Some of the ions that are used in chemical dry etching is Sulfur Hexafluoride(SF_6) nitrogen trifluoride (NF_3) chlorine gas (Cl_2) or fluorine(F_2)



→ Chemical Dry Etching



→ Plasma Dry Etching.

Reactive Ion Etching:- (RIE)

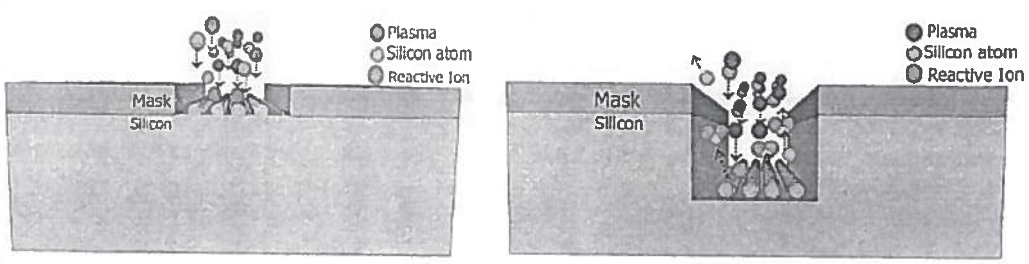
RIE uses both physical and chemical mechanisms to achieve high levels of resolution.

This process is one of the most diverse and most widely used processes in industry and research.

This process is much faster since the process combines both chemical and physical interactions. The high energy collision from the ionization helps to dissociate the etchant molecules into more reactive species.

In the RIE process, Cations are produced from reactive gases which are accelerated with high energy to the substrate and chemically react with silicon.

Typical RIE gases for Si are CF_4, SF_6, $BCl_2 + Cl_2$.



Silicon Micromachining:-

There are two types of Silicon micro-machining

1.) Bulk micromachining.
2.) Surface micromachining.

Bulk Micromachining:-

Bulk micromachining describes the fabrication Process of a device taking advantage of all three space dimensions.

Uses Single Crystalline Silicon.

The bulk material of the substrate along the thickness direction is etched by Wet or dry etching to realise 3D micromechanical structure.

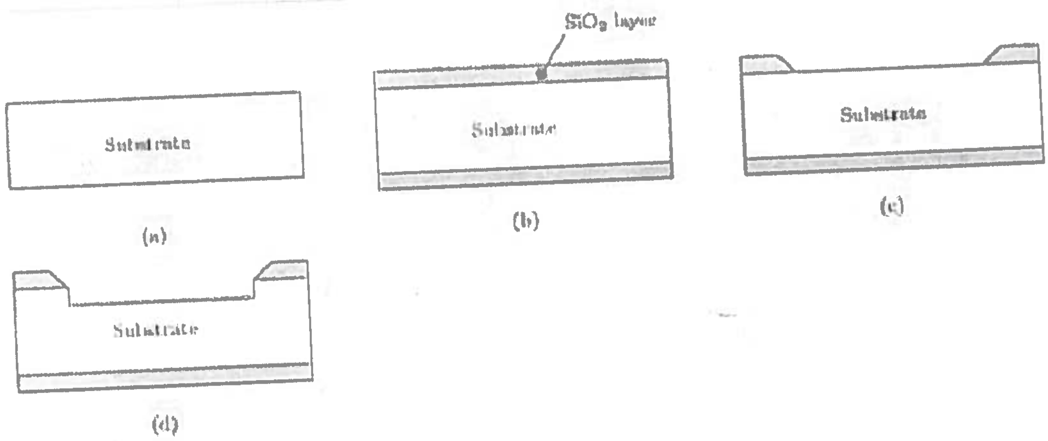
Device thickness is Controlled by etching Process.

Typical structures obtained by anisotropic or isotropic Wet etching through Complete of a bulk Silicon of a CMOS wafer includes membrane structures Consisting of the remaining dielectric CMOS layers.

Silicon wafer is oxidized to get silicon dioxide top and bottom.

Top side of wafer is preserved. Bottom side of wafer is exposed with UV rays by using lithographic technique. Now we etch the wafer by using either KOH or DP solution so that silicon is etched. Unmasked area is etched. The other regions are protected by silicon dioxide.

Using Bulk micromachining, Cantilever, Nozzle, Tuning forks and Silicon stencil mask can be made.



There are various chemical etchants we use for bulk micromachining.

1.) EDP Etching :- Ethylenediamine pyrocatechol.

We use three chemicals 1.) Ethylene diamine
2.) Pyro Catechol.
3.) Water.

They are mixed in a stoichiometric ratio and then we go for etching silicon at a particular temperature.

Features:-

→ Etch rate depends on temperature, Composition of etchant and density of atomic bonds on exposed silicon.

typical etchrates for (100) silicon:-

70°c	14 μm/hr
80°c	20 μm/hr
90°c	30 μm/hr = 0.5 μm/min
97°c	36 μm/hr.

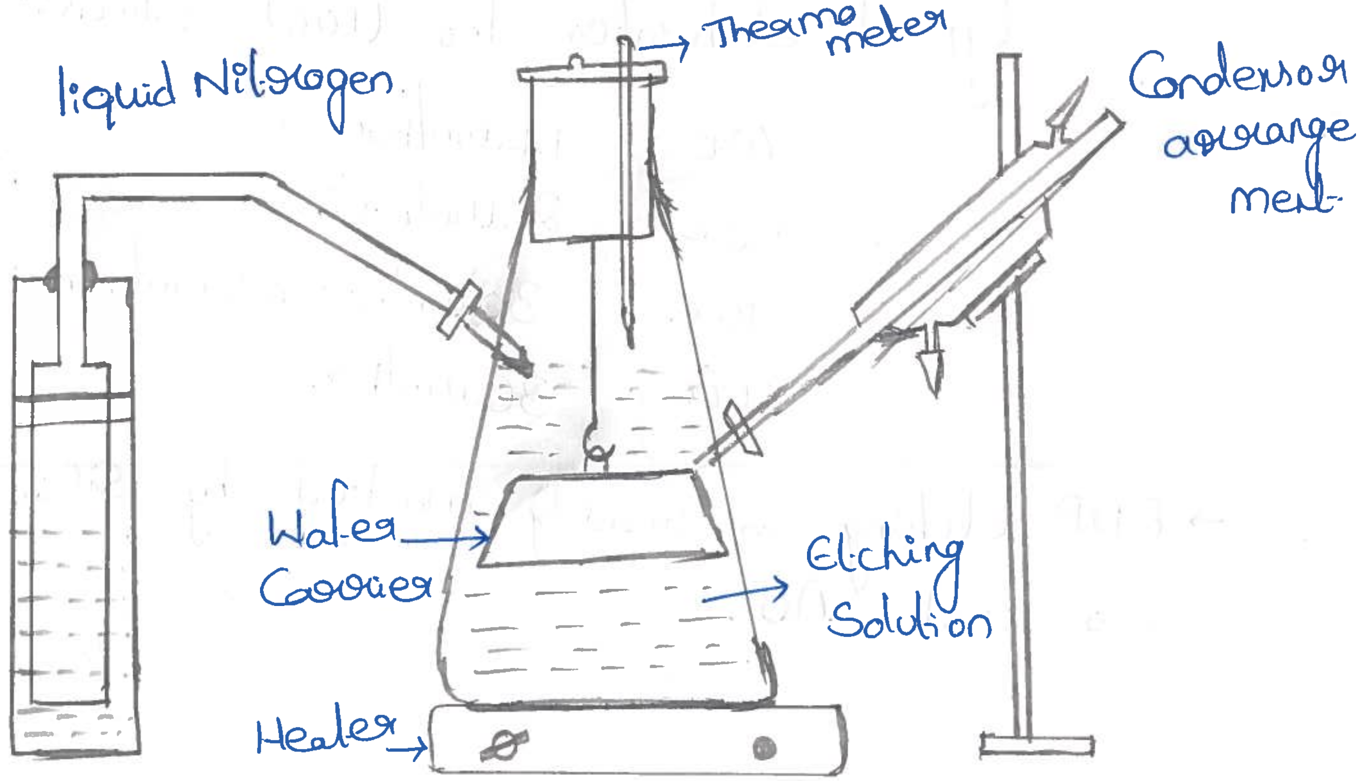
→ EDP etching is readily masked by SiO_2, Si_3N_4, Cr and Au

→ Very thin membrane of uniform thickness Can be Created by forming a heavily boron (p^+) layer.

→ Density of atomic bonds on exposed silicon depends on Crystallographic orientation. In different planes the atomic density of silicon are different.

→ EDP is very Corrosive, very Carcinogenic and never allowed near mainstream electronic micro fabrication.

→ Etch stop technique is very simple.



EDP is dependent on temperature.
Thermometer measures the temperature, so that you can adjust the temperature by controlling the heater.

Etching also depends on etchant concentration. Because of reaction during etching the concentration may degrade.

Etching is done at high temperatures in the range 100 to 110°C.

The etching solution evaporates if the solution evaporates concentration increases. So evaporation has to be stopped this is done by condenser arrangement which is done by cold water circulation around the tube.

The reason for liquid nitrogen evaporator is etching is highly sensitive to the environment if etching is done in open atmosphere so there will be lot of oxygen and hydrogen. So in order to prevent oxidation insulated thermocol chamber is used which contain liquid nitrogen. liquid Nitrogen will evaporate depending on temperature that flows to conical chamber so the result will be in

nitrogen ambient and temperature is
Controlled.

Composition of EDP solution:-

50 mole percent water
40 " " ethylene diamine
4 " " Pyrocatechol

→ KOH Etching:- Potassium Hydroxide Etching

* Heated KOH Solutions can be used for Preferential Crystallographic etching of silicon (si). The etch rate depends on ~~KOH~~ dopants doping and Crystallographic orientation of the si and Concentration of KOH used.

* Due to presence of alkali metal (Potassium) makes this completely incompatible with MOS or CMOS processing.

* Comparatively safe and non-toxic

* Provides smooth edge profile
* KOH is popular as silicon anisotropic etchant.

→ The etch ratio is large in KOH Compared to EDP.

→ Etch rate is higher in 100 to 111 etch rate ratio.

→ KOH is much useful to etch deep trenches in 110 silicon than 100 and 111 silicon.

→ KOH Concentration is typically 10 to 50%.

→ Isopropyl alchol is added to improve selectivity in passivation.

→ Si_3N_4 is an effective masking film for KoH etchants as selectivity of SiO_2 is less than Si_3N_4 at various Concentrations of KOH.

* Procedure:-

→ Put KOH solution in glass Container

→ Warm to 80 deg c on hot plate.

→ Place patterned wafer in the KOH solution

→ The KOH Solution will bubble at the exposed silicon sites while etching occurs.

* The etch rate for 30% KOH at 80°c is 1 micron/minute.

→ **TetraMethyl Ammonium Hydroxide (TMAH) Etching:-**

The biggest advantage of TMAH is it does not attack aluminium.

Aluminium which is used for interconnect lines it ~~does not~~ will never be disturbed or attacked by TMAH.

TMAH is CMOS Compatible and it has excellent silicon etch rate.

TMAH is Anisotropic etchant for silicon.

TMAH is Commonly used for fast removal and Silicon micromachining.

TMAH has high etching selectivity over SiO_2 and Si_xN_y.

Easy to handle since TMAH is non-toxic.

Disadvantages:-

→ Smaller <100>/<111> Etching ratio

→ Poor Boron etch stop performance.

TMAH etching Rate depends on Crystal orientation, Composition and temperature.

TMAH etch rate is similar to KOH and varies similarly in accordance to the atomic organization of Crystallographic plane.

TMAH etch rate varies exponentially with temperature.

Etchant	Temperature	Direction	Etch rate um/min
5% TMAH 95% H_2O	80	(100)	0.87
	90		1.4
	80	(110)	1.4
	90		1.8
	80	(111)	0.030
	90		0.034
22% TMAH in H_2O	90°c	(100)	0.9
		(110)	1.8
		(111)	0.018
22% TMAH in H_2O + 1% surfactant	90°c	(100)	0.6
		(110)	0.1
		(111)	0.009
22% TMAH in H_2O + 0.5% surfactant	90°c	(100)	0.6
		(110)	0.12
		(111)	0.01

Surfactant:- Compounds lower surface tension between two liquids.

LIGA:-

LIGA is the abbrevation of 3 German words
→ Lithographie (lithography)
→ Galvanoformung (electroplating)
→ Abformung (molding)

* The primary advantage of LIGA process is it's Capability to make large aspect ratio structure however the shape of the structures remain flexible. (Ex: gears, nozzle etc).

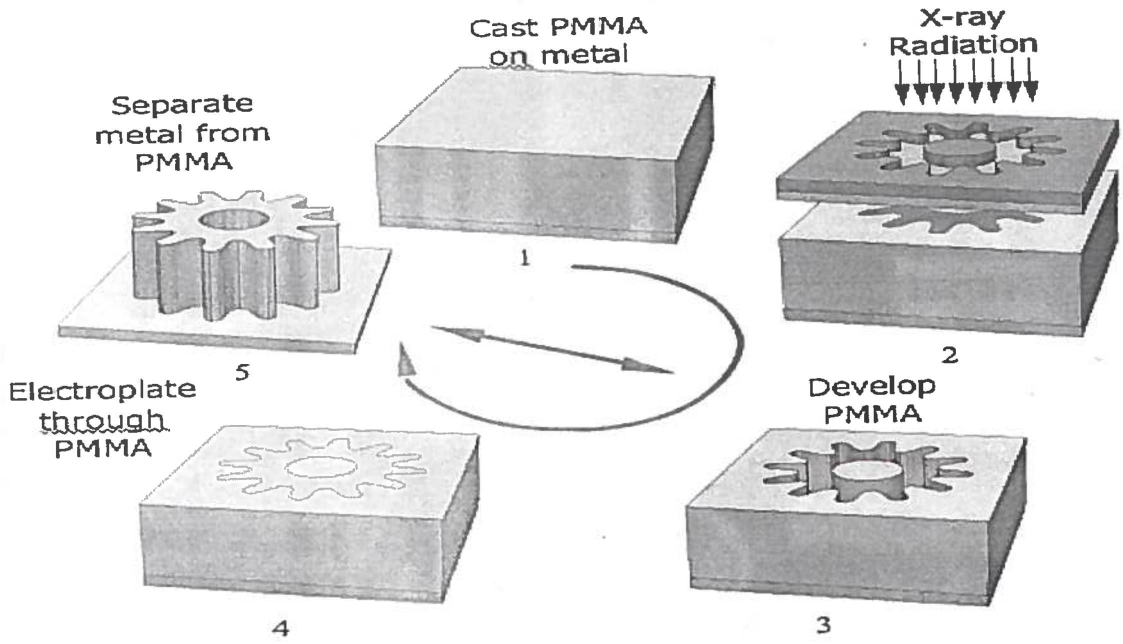
* LIGA process Can also be applied to make movable structures and stepped structures by adding the Concept of Sacrificial layer.

* aspect ratio (1000μm thick only several micron wide).

Steps:-
→ Casting a layer i.e x-ray sensitive PMMA on a suitable substrate.
→ A special x-ray mask is used for the selective exposure of the PMMA layer using x-rays.

→ After development of patterned PMMA acts as a Polymer mold and is placed into an electroplating and Nickel is plated into the open areas of the PMMA.

The PMMA is then removed thereby leaving the metallic microstructure.



LASER

laser Micromachining:-

LASER:- Light Amplification by Stimulated Emission of Radiation

LASER Can generate an intense amount of energy in very short pulses of light and direct that energy onto a selected region of material for micromachining.

Types of lasers:- CO_2, Excimer. Nd: YAG (Neodymium-doped Yttrium aluminium garnet)

Factors that define to use a particular laser includes wavelength, Spatial modes. energy, Power, material type, feature sizes Processing speed and Cost.

The action of CO_2 and YAG laser is essentially a thermal process.

Focusing optics are used to direct a Pre determined energy/Power density to a well defined location on the work piece to melt or Vaporize the material.

Another mechanism, which is non thermal and referred to as Photoablation occurs when organic materials are exposed to ultraviolet radiation generated from Excimer.

* laser micromachining: cutting, drilling, welding modifications in order to achieve small features.
* lasers have been in use in various industrial sectors such as automotive and aerospace for performing cutting & welding of materials.
* In microengineering applications of lasers where pulsed lasers in particular have played a major role in development of numerous micro systems technology.

Applications:-

→ For drilling micro holes

→ In the manufacture of micro channels and micro holes in integrated chips and micro chips.

Advantages:- Easy capability of being automated

Straight forward process monitoring.

Forceless and contactless machining.

Minor-heat affected zone.

High precision

No solvent chemicals used

Disadvantages:- → Equipment required for micromachining is very costly than other cutting process

→ Need highly skilled persons to operate micro machining systems.

→ Reflect laser light can present a safety hazard.

→ Material limitations.

Etch Stop Techniques:-

Etch stop is defined as a technique that allows termination of the etching process at a controllable depth.

A region where wet (or dry) etching tends to slow down (or halt) is called an etch-stop.

Etch process can be made selective by the use of dopants -

heavily doped regions etch more slowly or even halted.

Electromechanically when observing the sudden rise in current through etched n-p junction.

Two methods of etch stop:-

→ doping selective etching (DSE)

→ bias dependent etching (BSE).

Doping Selective Etching:-

Silicon membrane are generally fabricated using the etch stop phenomenon of a thin heavily boron doped layer.

Stopping effect is general property of basic etching solutions such as KOH, NaOH, EDP.

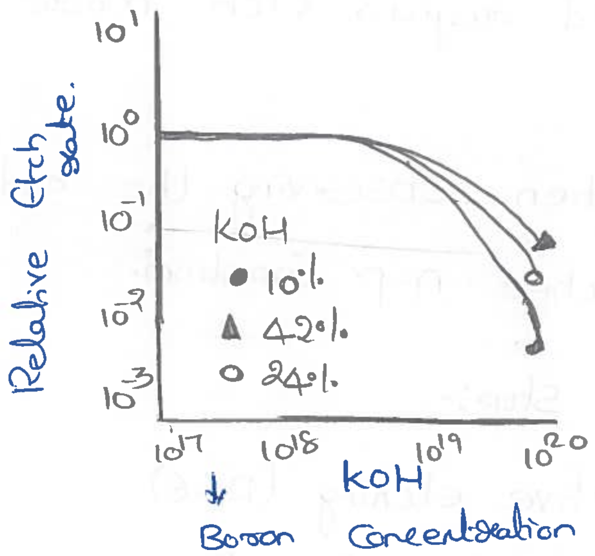
In fact a silicon substrate with a dopant concentration of 10^20 boron atoms/cm^3

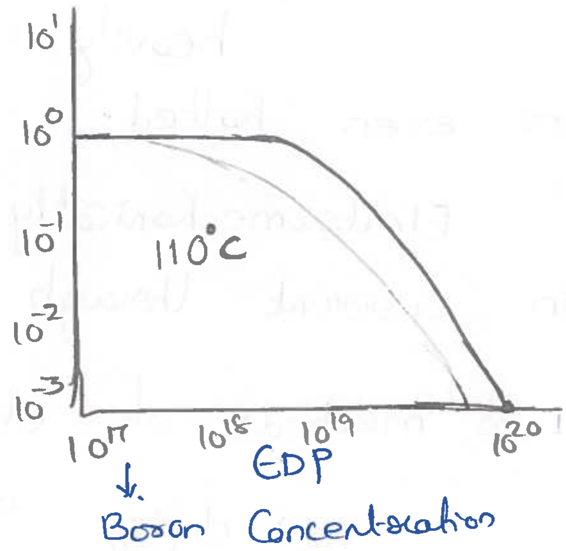
only has a etch rate of 1% of that of intrinsic silicon.

Before this method relied on bombarding of boron ions with high energy.

Penetration depends on the kinetic energy of the ions, Controlling the energy of ions can control the depth of the doped layer.

Etch stop layer buried in undoped etchable silicon.





Advantages :-

→ Relatively easy process

→ High selectivity and reliability.

Disadvantages:-

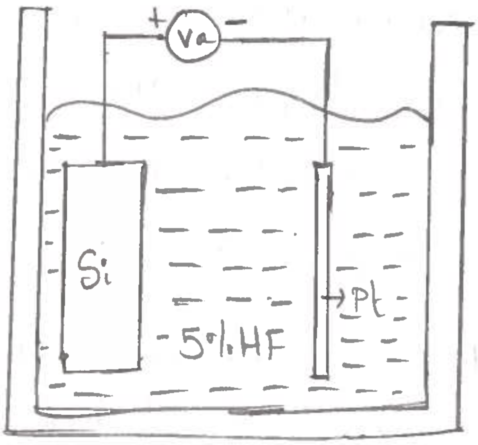
→ Excess boron doping prevents introduction of electrical components for sensing purpose into the microstructures.

→ High levels of boron introduce mechanical stress into silicon and may cause buckling or even fracture in a diaphragm of a structure.

Electrochemical Etch/Bias Dependent Etching (BSE):-

Etch Stop achieved by a Voltage potential and the use of different chemicals.

Electrochemical passivation technique are used as an alternative to heavy boron-doping.



In bias dependent etching. oxidation is promoted by a Positive voltage applied to the Silicon wafer. Causing accumulation of holes at the silicon ~~wafer~~ Solution interface.

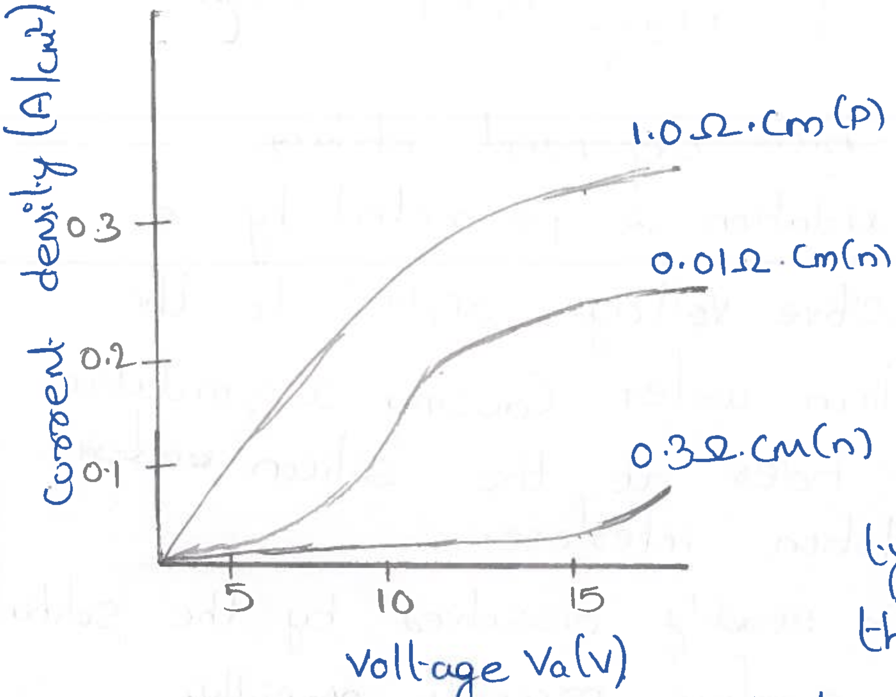
While the oxide is readily dissolved by the solution ∵ oxidation at the surface proceeds rapidly. Holes such as H^+ ions are transported to the Cathode and released there as hydrogen gas bubbles.

The above fig shows an electrochemical cell that is used to etch Si in a 5% hydrofluoric (HF) Solution.

Cathode plate is made of platinum.

holes are injected to silicon electrode and they tend to reside at silicon surface where they Oxidise Si at the surface to Si^+.

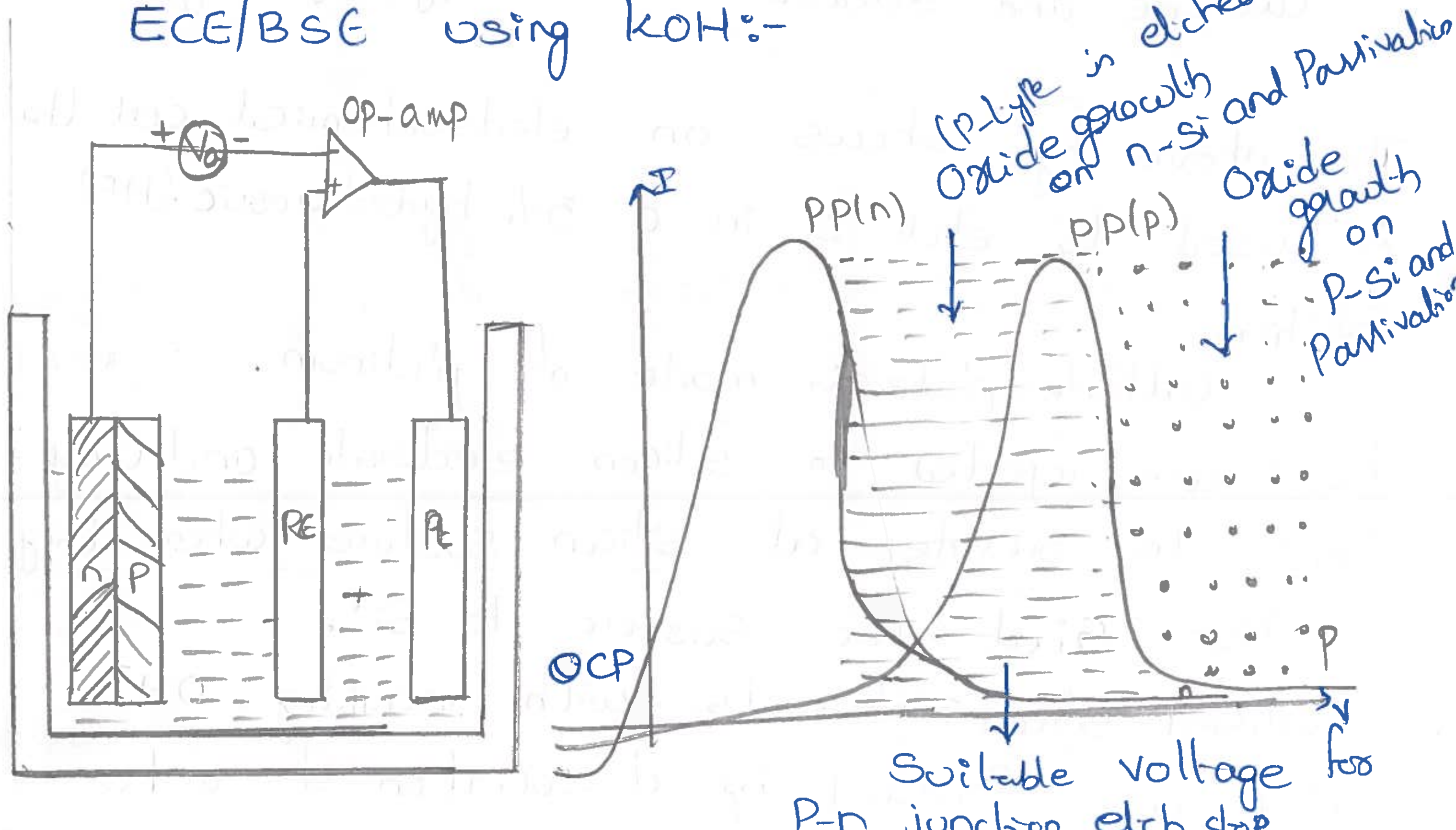
Oxidised silicon interacts with incoming OH^- that are produced by dissociation of water in the Solution to form unstable Si(OH). Which dissociates into SiO_2 and H_2 gas. The SiO_2 is the dissolved by HF and removed from the silicon surface.



Current density is very much dependent on type and the resistivity of silicon. (doping level).

This dependence on the type and resistivity is the property that is utilised in the electrochemical etch-stop Phenomenon.

ECE/BSE using KOH:-



Open Circuit potential (OCP):- Potential at which the current I is zero and the the passivating Potential as the potential at which current suddenly drops from its maximum Value.

The difference between HF and KOH etch is oxide is dissolved in HF solution where as oxide is not readily dissolved in KOH Solution.

When applying voltage between the two passivating Potentials of n-type and p-type on expects the characteristics as shown in above fig. only p-type Sample and not the n-type sample would be etched. That is the doping selective effect is used as an etch stop.

The etch rate is not proportional to the current.

The etch rate attains a maximum at the OCP and slows down at the PP (current is maximum). Eventually the etch stops when the current drops.

chemical reaction takes place at silicon surface with sequential attack of Si-Si bonds by H_2O and OH. resulting in discharge of OH.

$$Si-Si + H_2O \longrightarrow Si-H + Si-OH.$$

It is followed by rapid chemical reaction that oxidises underlying bonds. The reduction oxidation couple OH^-/H_2O is assumed to supply the species for etching

$$Si-Si + Si-OH + OH^- \longrightarrow Si-O^- + Si-OH + H_2$$

The hydrogen gas produced per Si atom has been measured by palik in 1985 was found to be $2H_2$ per Si.

The net reaction for dissolution of silicon atom would therefore be

$$Si + 2HO + 2OH^- \longrightarrow H_2 + Si(OH_2)(O^-)_2$$

limitation:-

Effect of reverse bias leakage current in the junction.

Surface Micromachining:-

Surface Micromachining basically involves depositing thin films on the wafer surface and selectively removing one or more of these layers to leave free standing structures.

It was initiated in the 1980's and is the newest technology in production.

Material is added to the substrate in the form of layers of thin films on the the surface of substrate.

These layers either by structural layers or acts as spacers, later to be removed is known as sacrificial layers.

Hence this process usually involves of two different materials:-

1.) Structural material (Polycrystalline, silicon nitride, and aluminium).

2.) Sacrificial material (usually oxide).

These layers are deposited and subsequently dry etched in sequence. With the sacrificial material being finally wet etched away to release the final structure.

A typical surface micromachined cantilever beam :-

→ A sacrificial layer of oxide is deposited on the silicon substrate surface using a pattern and photo lithography.

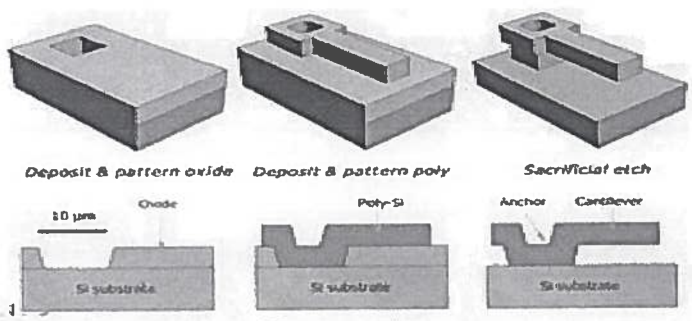
→ A poly silicon layer is then deposited and patterned using RIE process to form a cantilever beam with an anchor pad.

→ The wafer is then wet etched to remove oxide i.e sacrificial layer releasing and leaving the beam on the substrate.

→ More complex MEMS structures can be achieved using structural polysilicon and sacrificial ~~layer~~ silicon dioxide. including sliding structures, actuators and free moving mechanical gears.

Surface micromachining

How a cantilever is made:



Sacrificial material: Silicon oxide

Structural material: polycrystalline Si (poly-Si)

→ Surface micromachining structures can be an order of magnitude smaller than the bulk micromachined structures.

→ The main advantage of surface micromachining structures is their easy integration with Integrated Circuit Components.

Problems in surface micromachining:-

Surface stiction:-

The surface tension of the water under structures pulls them down to the surface of the water and causes them to adhere permanently to the wafer surface. It accounts structural failure.

Methods to Prevent surface tension:-

→ Freeze drying of the final rinsing Solution. (Sublimation).

→ Use of integrated polymer support structure during release etching & ashing PR.

Micromachining of Quartz:-

Quartz is a mineral that contains silicon dioxide (SiO_2). Quartz has a unique crystalline structure in tetral hedral co-ordination. It is also known as silica.

It is a unique semiconductor material for microelectronics, VLSI and MEMS, integrated sensors. Silicon dioxide quartz is crystallographic form. Here in quartz silicon dioxide which is used for masking is amorphous in nature.

Quartz is a crystal material:-

- → It will have piezoelectric property
- → low temperature coefficient
- → high mechanical strength.
- → Thermal stability is very high.
- → SAW (Surface acoustic Wave) devices special MEMS and MOEMS can be made using ~~MOE~~ Quartz.

Comparision of silicon vs Quartz

	silicon	Quartz
Resistivity	10^3	10^{15}
Dielectric Constant	12	4.5
Density ($gm.cm^{-3}$)	2.3	2.65

	Silicon	Quartz
Young's Modulus	1.7×10^{11} (110)	7.6×10^{13} (1 .Z)
	1.9×10^{11} (111)	9.7×10^{13} (11 . Z)
Bending strength	7.20×10^{7}	9×10^{7}

We normally make out of quartz are
:- Cantilever Beams
:- Miniature tuning forks
:- Dual and double bended tuning forks.
:- Membranes

MEMS applications:-

→ Oscillator structure:-
Quartz is a piezoelectric material.
Quartz can get a very good crystal oscillator.
by micromachining.
∵ Resonance frequency depends on the structure of the Piezoelectric material.

→ Accelerometer Gyros can be made out of Quartz.

→ Actuators because it is a piezoelectric dependent system.

→ Vibrators :- As Quartz is a piezoelectric material. it vibrates if some electric signal is incident on that Quartz.

→ Optical Choppers.

→ Development and optimization of selective deposition of electrode materials at the sidewall of Quartz micromachined structures through Vaccum masking.

→ ~~Aniso~~ Anisotropic Quartz Etching

* 300 A chromium & +3000 A Gold film is used for deposition (Masking Material) followed by Patterning.
* Deep Etching in HF based solution at Various temperatures through chromium gold Patterned mask.

  Etching in 80% HF at 80°c is fast where large kinks appear at both X and Y sections.
* Etching in Saturated ammonium fluoride NH_4HF_2 Solution at 80°c yields low etch rate and smaller kinks.
* IF lot of kinks or facets are produced then the irregular structure of the quartz Crystal will be produced.

* Quartz is temperature insensitive and radiation hard.

Piezoelectric property does not change with temperature.

In space a lot of alpha ray, beta ray, gamma rays are present in addition with UV rays.

In case of silicon piezoresistive material can produce lot of carrier electrons and holes so they generate some current because of radiation. That possibility is not there in case of quartz.

Quartz Micromachining:-

→ Standardisation of anisotropic etching of single crystal quartz.

→ For etching one have to select proper masking material that can sustain prolonged etching in fluoride based solution.

→ All etching solutions of quartz are fluoride based.

→ Development and optimization of lithography process for micromachining of quartz which requires double side alignment.

Ex:- In designing of oscillator, Resonant frequency of that microstructure depends on it's shape. that is why ammonium fluoride NH_4HF_2 is used at low temperature to get rid of crystallographic facets or kinks.

Schematic Y-section → of a Z-cut quartz etching at 80°c

(a) 80% HF

(b). Saturated NH_4HF_2.

* kinks or Facets will disturb performance.

Etching Solutions:-

→ Anisotropic etchant for Quartz:-

$HF + NH_4HF_2 + H_2O$

etch rate at 22°c is 6µm/hr

at 80°c is 16µm/hr.

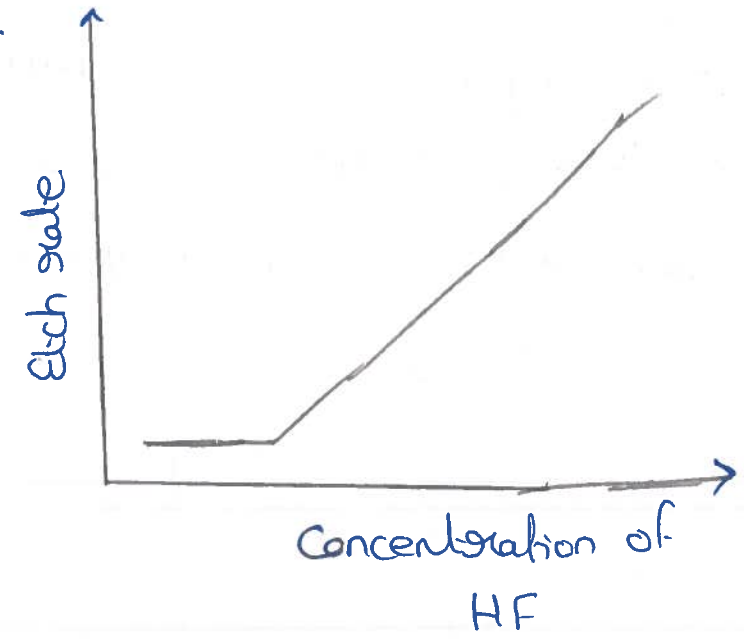
→ chromium etchant:-

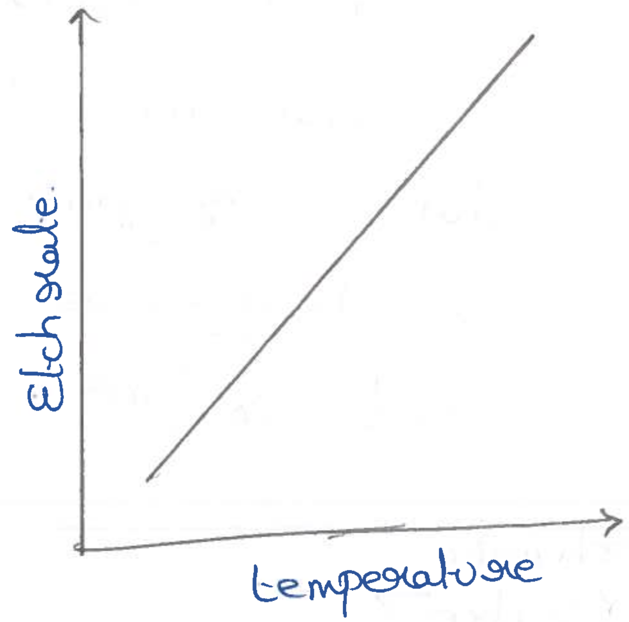
ceric ammonium nitrate + Perchloric acid + Water

the etch rate at 22°c is 100Å/min.

→ Gold Etchant:-

Standard iodine based gold etchant from Transene, USA the etch rate at 22°c is 0.1µm/min.





While using.
* HF where etch rate depends on both
Concentration of HF and heating of HF
the Solution.
i.e temperature of heating the Solution.

Microstereolithography:-

Stereolithography is a form of 3-D printing technology used for creating models, prototypes, patterns and production Parts layer by layer by using photopolymerization.

Stereolithography is a rapid prototyping and manufacturing technology that enables the generation of Physical objects directly from CAD data data files.

It was first introduced by

Kodama - Japan 1981
Andre etal - Europe 1984
Hull - USA 1984

Stereolithography used to make microparts known as Micro stereolithography.

Stereolithography is an enabling technology to make parts for MEMS devices in materials other than silicon.

Micro stereolithography permits fabrication of true 3-D devices on the μm to mm scale (micrometer to millimeter)

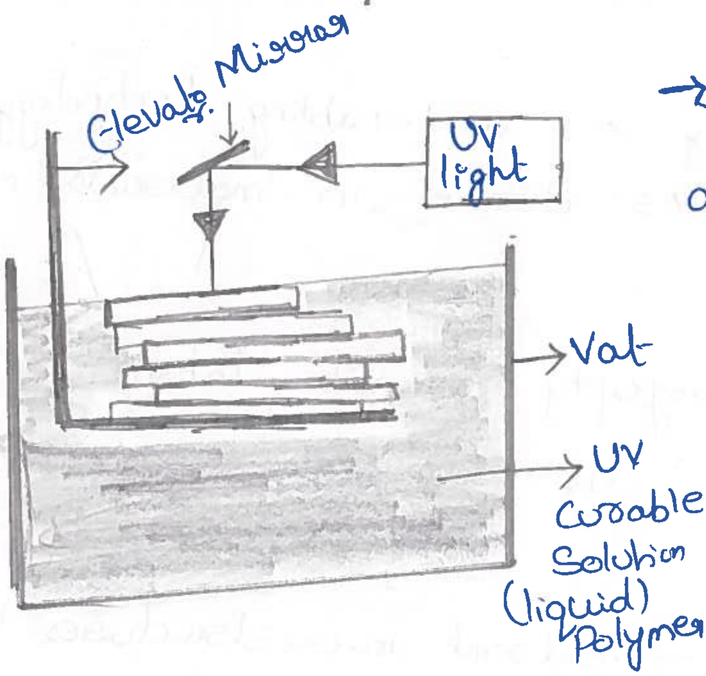
Curvilinear and re-entrant microstructures that are difficult to make using conventional micromachining.

Microstereolithography has some similarities with LIGA and some times micro stereolithography or stereolithography is known as Poor man's LIGA Process.

Definition of a 3D model using CAD → Desired polymer object is Written into UV-curable resist layer by layer. → The entire structure is obtained.

Slicing 3D model into series of closely spaced horizontal planes that represent XY cross section of the 3D object with different Z-Values ↑ (to Definition of a 3D model using CAD)

Slicing 3D model ... → The 3D models are translated into numerical Control code and merged ~~with~~ together with build file to Control UV light Scanner and Z translator ↑ (to Desired polymer object is Written into UV-curable resist layer by layer)



→ Starting from a 3D image a part is built slice by slice (layer by layer) from bottom to top in a vessel of liquid polymer that hardens when struck by a laser beam.

→ Creating a 3D object using a Computer Controlled laser to build the required structure, layer by layer. It does this by using a UV curable resin known as liquid polymer that hardens when struck by a laser beam.

Layer preparation:-

Foundation of each layer much satisfy following requirements:

→ Surface must be at a Controllable distance above previously built Solidified Cross Section of the part.

→ Maintained precisely at the focal plane of the imaging system.

→ Any shrinkage during curing must be Compensated by the excess resin in the VAT.

Micro stereo lithography:- (MSL)

→ It is also Called microphotoforming and was first introduced by Ikuta and HiroWatari in 1993.

→ The resolution of MSL is better than SL.

→ layer thickness Varies from 1 to 10um where as in Stereo lithography ~~layer~~ layer thickness are 100 to 1000um.

→ Submicron Control of both X, Y, Z translation Stage and Small UV beam Spot enables Precise fabrication of Complex 3D micro structures.

→ A 3D structure is built by repeated Scanning of either the light beam or the work Piece layer by layer.

Basic principles of stereolithography:-

→ Stereolithography (SL) ~~process~~ is a photopolymerisation process, where under exposure of UV radiation small molecules in a resin/resist form larger molecules.

Three photopolymers used in stereolithography are acrylate, epoxy resin and vinyl ether.

→ The important point in the optical source is the intensity of UV radiation or laser radiation is Gaussian kind in nature.

If it is a Gaussian kind of nature. the intensity changes as for the depth.

→ Two most critical parameters (curing depth and line width) need to be carefully controlled and are determined from the beam distribution and absorption of radiation in the resist.

→ Beer lambert law:- (Wayne, 1998): $I_t/I_0 = \exp(-\alpha c d)$

I_t, I_0 are transmitted light and incident light intensity. α = absorption coefficient

C: concentration of the absorber.

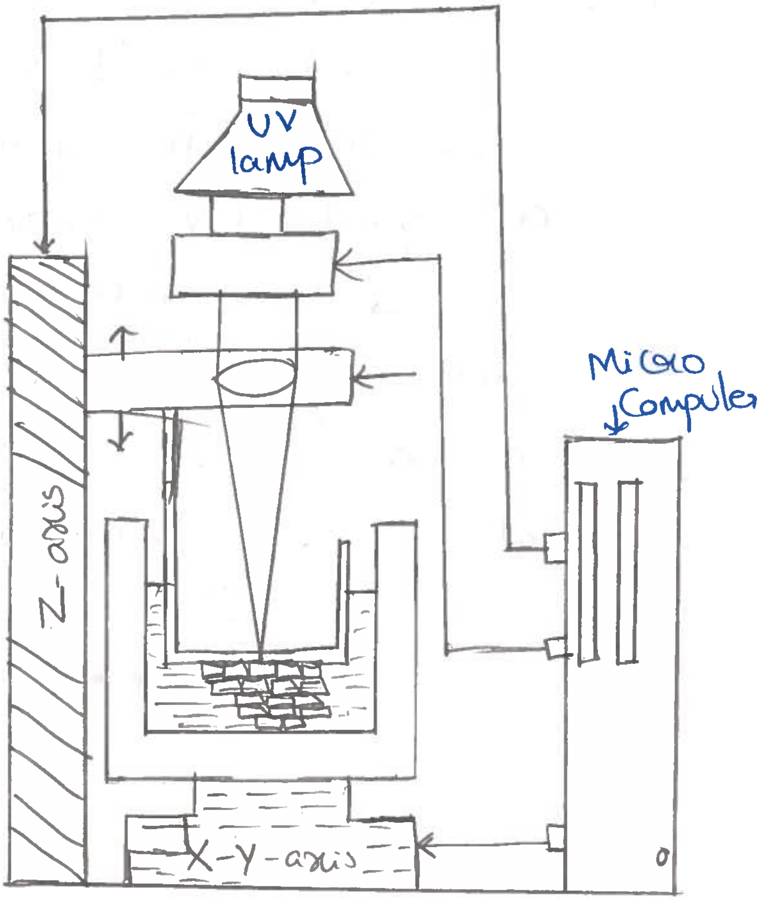
d = distance the light has transmitted.

Irradiance (radiant power/unit area), $I(x,y,z)$ at any point with in the resin can be related to the irradiance incident on the resin surface.

→ Relation ship between the curing depth (cd) and line width (l_w) is given by $l_w = 2W_0\sqrt{(C_d/2d_p)}$.

→ Several Scanning methods are:-
- → Classical Micro stereolithography.
- → Integrade harden(IH) Process.
- → Super IH Process.
- → Mass IH Process.

Integrated Harden (IH) Process:-



light Source is an UV lamp and the beam is focused on to resin surface through a glass window.

The focal point of the apparatus remains fixed during the fabrication and the work Piece is in Container attached to an X-Y Stage so that the glass window is attached to the z-plane. So that layers of precise thickness Can be Prepared.

- → UV beam spot size is 5μm.
- → Positional accuracy is 0.25μm and 1.0μm in the z-direction.
- → Minimum size of the unit of harden polymer is 5μm × 5μm × 3μm (x, y, z) where as Maximum size is 10mm × 10mm × 10mm.
- → Fabrication speed is Slower than classical MSL.

Limitations of IH Process:-

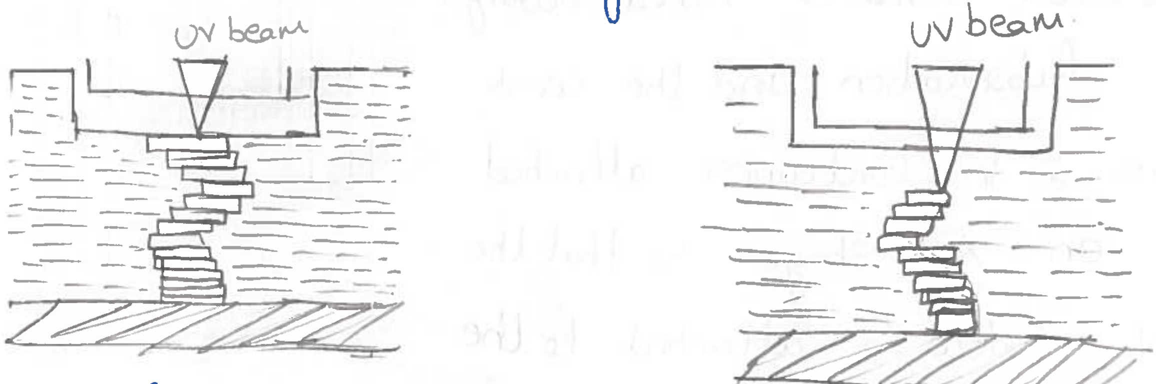
→ The depth resolution is limited by the thickness of layer.

→ A significant of the surface tension of the liquid monomer decreases the precision of the fabrication process.

Super IH Process:-

→ It solidifies the monomer at a specific point in 3-D space by focusing laser beam into a liquid UV - curable monomer.

→ 3-D microstructure is now fabricated by scanning the focused spot in all 3 dimensions inside the liquid, thus eliminating the need for support material or sacrificial layer.



(a) Conventional MSL (IH)

(b.) Super IH Process.

In IH Microstereo lithography the focal plane of the beam is fixed it can scan only xy direction where movement is not done in z- direction. Z means structure container moving in z direction. In Super IH process the beam goes deeper into polymer so the beam moves not only in XY plane but also in z-plane.

Ceramic MSL:-

→ Ceramic Materials have useful properties such as high temperature or chemical resistance high hardness, low thermal Conductivity, ferroelectricity and piezoelectricity.

→ 3-D Ceramic micro structures are used in applications such as microengines and microfluidics.

→ Unlike Conventional silicon micromachining MSL Can be used to build the Complex Ceramic 3-D microstructures in a rapid free-form fashion without need of high pressure / high temperature.

Process:-

→ The resin system for ceramic MSL is Composed not only of the monomers and photoinitiators that are used in polymer MSL but also of ceramic Powder, dispersants and diluents.

→ Dispersants and diluents are used to obtain a homogenous Ceramic suspension with a relatively low Viscosity.

→ UV polymerisation, the ceramic particles are bonded together by the polymer and the ceramic body is formed.

Fabrication of Micromachined Microelectrodes:-

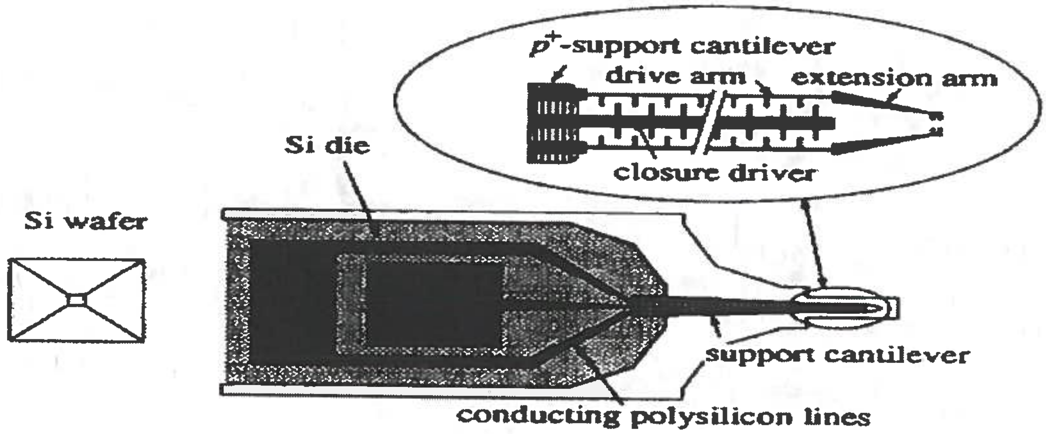
MicroGrippers:-

Microgrippers that are capable of handling micron-sized objects have applications in biomedical as well as in microtelerobotics.

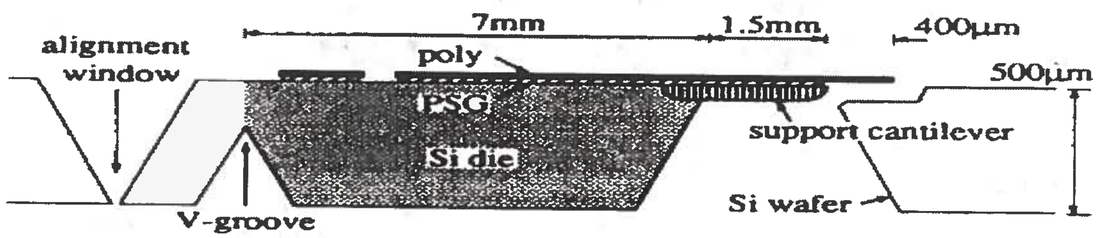
The fabrication of the gripper makes use of combined surface and bulk micromachining.

(fig (b)) Schematic of the microgripper unit before it is freed from silicon wafer.

The element consists of a closure driver and two drive arms which connect to extension arms that extend to the gripper jaws.



(a)

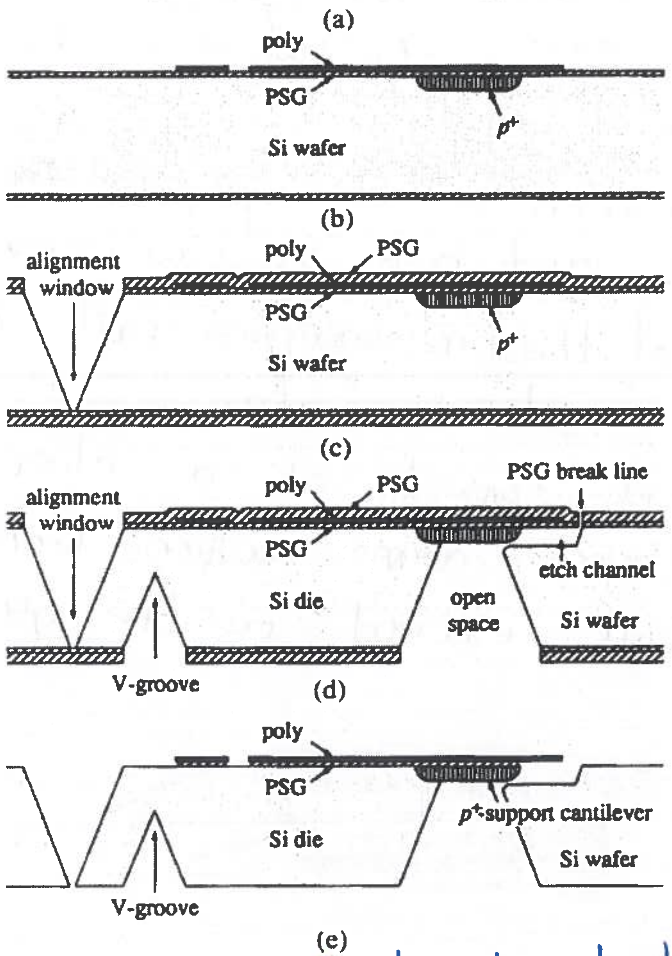


(b)

When voltage is applied b/w the closure driver and the driver arms the drive arms being flexible bend to close the gripper jaws.

The cantilever beam heavily doped with boron is defined geometrically by etch stopping in EDP. 12 um thick

→ With thermally grown SiO_2 as the masking layer boron is diffused at 1125°C for 15 hr.
The masking SiO_2 layer as well as the boron silicate glass (BSG) grown during the boron diffusion



→ low pressure chemical vapor deposition (LPCVD) of a 2µm thick phosphosilicate glass (PSG) layer a 2.5µm thick undoped polysilicon layer is deposited by LPCVD.

→ The Poly silicon is then patterned anisotropically by Reactive ion etching.

→ To make front to back alignment reference an alignment window is formed by patterning the PSG on the wafer frontside and the lay anisotropically etching in EDP.

→ The Open space is etched from backside by RIE.

→ A final timed etch of PSG fully exposes the overhanging polyisilicon microgripper by removing PSG from the top and bottom.

→ All Polysilicon conducting lines of the structure have a PSG layer left underneath them which anchors them to the substrate.

Micromachined mechanisms Micromotors:-

Fabrication process:-

The basic process uses two polysilicon and two silicon dioxide depositions as well as four photolithography steps.

1.) Center-Pin Process:- (Bush Process):-

→ Deposition of polysilicon the rotor is Patterned by RIE (Reactive ion Etching).

→ Deposition of Poly silicon where the centre pin design and eliminate rotor to substrate striction Problems.

→ Deposition of 2nd layer of SiO_2

→ Deposition of polysilicon the center pin is defined in fig(d).

Where if any Sacrifice layer present is removed by HF to release the rotor.

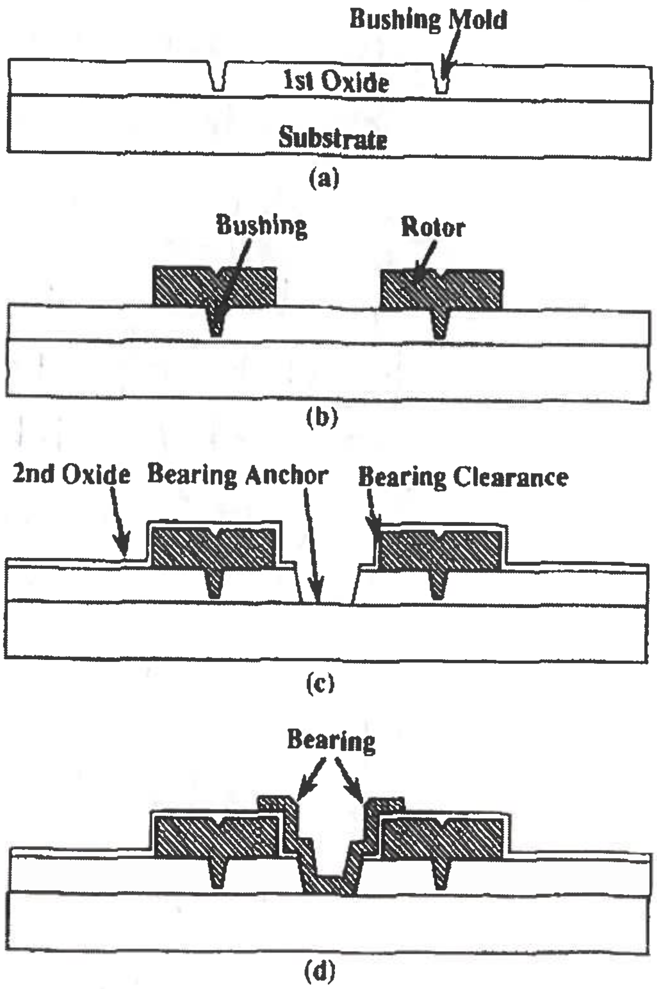
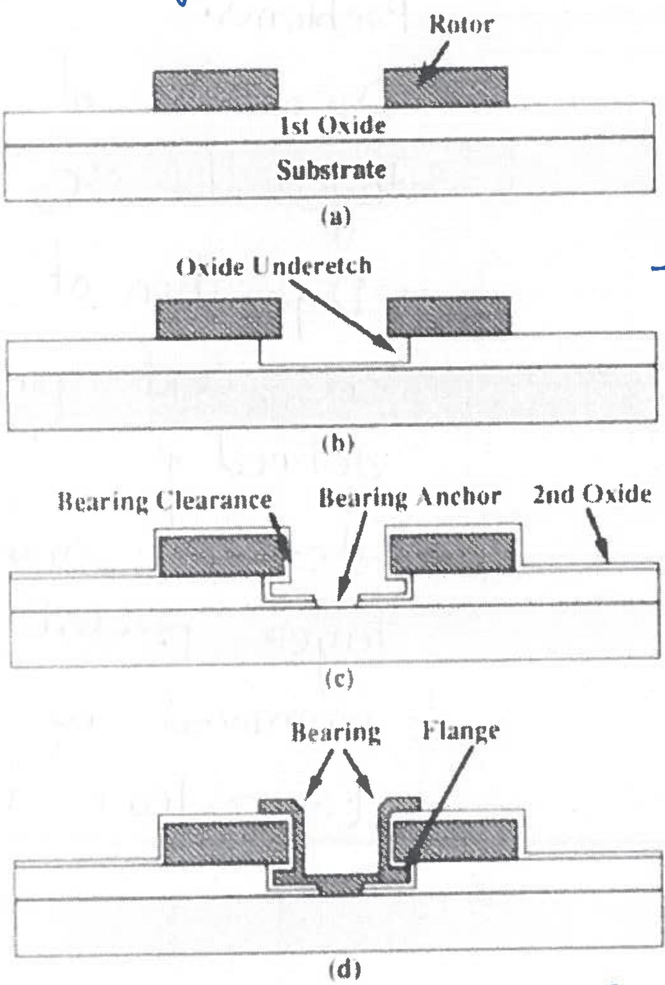


fig:- Rotor on a Center pin fabrication process.

Flange Process:-

The flange process considers the implementation of a rotor which is free to turn about a center bearing.

This process uses 2 poly silicon and 2 SiO_2 depositions as well as 4 photolithography steps. The over all process is similar to the center pin (Bush) process. only uses minor modifications to accomplish the flange bearing. The flange process provides more flexibility.



→ After deposition of SiO_2 layer Poly silicon is deposited.

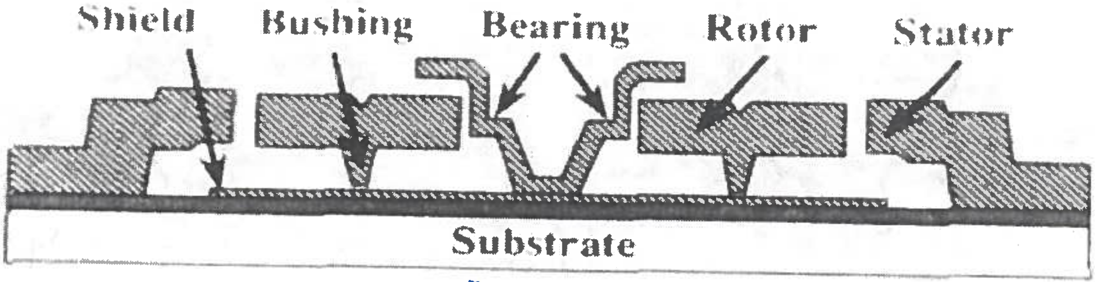
→ The Rotor is patterned to that of poly silicon layer by RIE.

→ Oxide at the inner radius is ~~understretched~~ underetched.

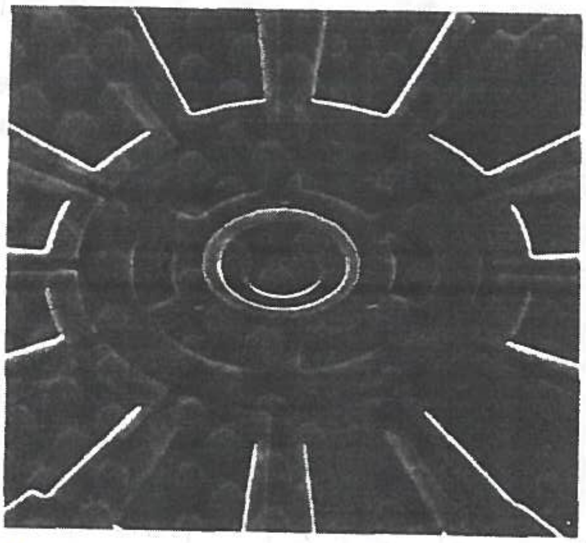
→ After a second blanket deposition of SiO_2 layer. a 2nd poly silicon layer is deposited.

The flange in bearing is functions in a similar manner to the bushings in center pin design.

→ If there is any sacrificial layer present the ~~wafer~~ design is dissolved in HF solution to release the rotor.



(schematic of micromotor).



(side drive of motor).

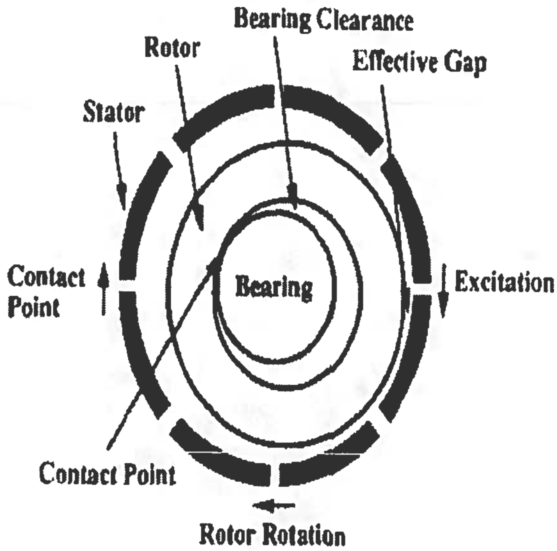
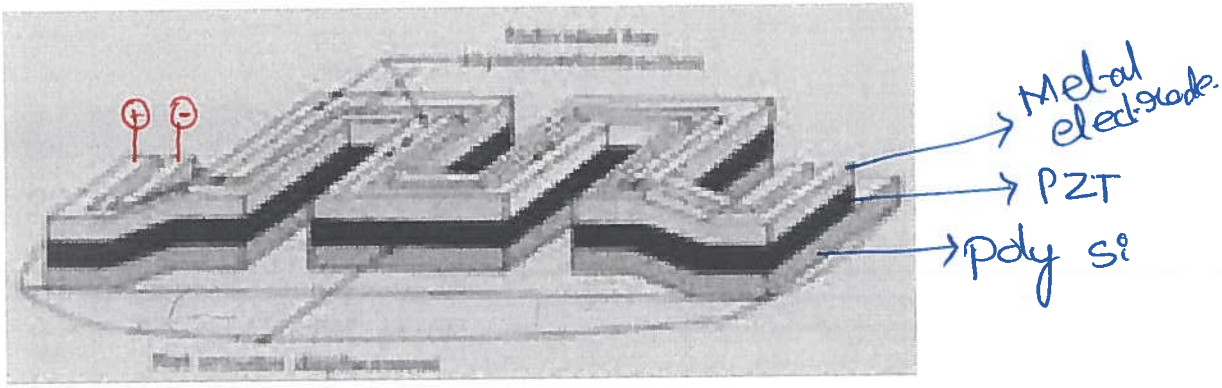
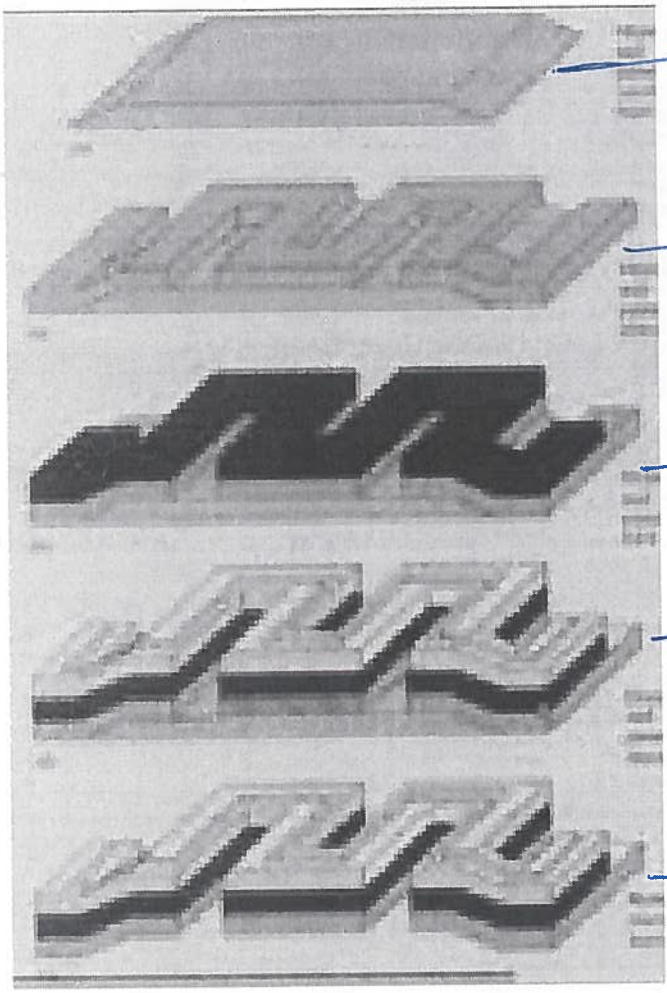


fig: Plan View of the micromotor.

Linear Motion Micro actuators:-

If there is any repulsion in a microstructure by applying some electrical sig then it is known as actuator.



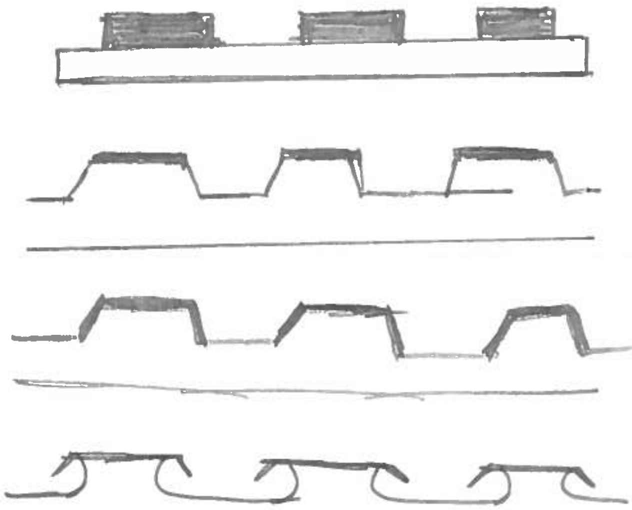


→ The linear motion microactuator uses folded-path geometry when a voltage is applied to the top surface of a dual electrodes on

Piezoelectric thin film of PZT.

The PZT either expands or contracts it's length depending on the polarity of it's voltage with respect to poly-Si layer.

Silicon MicroVelcro:-



→ Isotropic and anisotropic wet etching have been used to fabricate a dense regular array of microstructure that can be used as a button snap/zipper in a 2-D configuration

The structure behave like "Velcro" material.

→ Thermal Growth of SiO_2 using photolithography to pattern array of rectangular island with one edge aligned 45° to the (110) flat.

... nanotechnology ...

... similar ... that ...

... a 2-D configuration

... like "Velcro" mechanical ...

→ Thermal Growth of ...

... pattern ...