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UNIT - I

M.E - Communication System

MEMS

MEMS

- Micro (small)
- Electro (electric components / functionality)
- Mechanical (Mechanical components / functionality)
- System (Integrated, system - like ~~functionality~~)

MEMS TECHNOLOGY

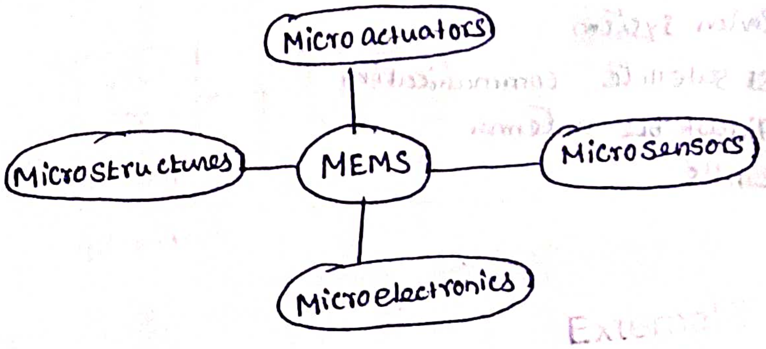
Introduction:-

* Micro - Electro - Mechanical System have been developed since the 1970's
* Miniaturized mechanical and electro Mechanical element using micro fabrication.
* Most Promising technology of 21st century.
* Fabricated using VLSI technology.
* wireless technology utilizes RF signal which is EM signal
* RF operates in the range 9KHz to 300GHz

Differences of IC Vs MEMS :-

MEMS	IC
* 3D complex structures	* 2D structure
* Doesn't have any basic building block	* Transistor is basic building block
* May have moving parts	* No moving parts
* May have interface with external Media	* Totally isolated with Media
* Functions include Biological, chemical, optical	* Only Electrical
* Packaging is very complex	* Packaging technique are well developed

Basic functional Element of MEMS :-

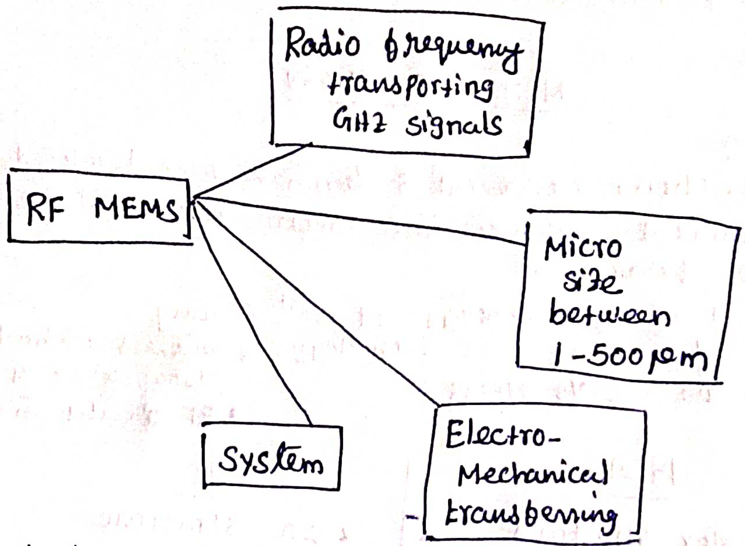


* converts physical stimulation, events and parameters to Electrical, Mechanical, and optical signals and vice versa.
* performs actuation, sensing and other function.

MEMS Benefits:-

* Micro size
* Integration with single chip
* Decreased cost of production
* Many new features
* Better performance than convention RF components

RF MEMS



* Micro system for radio and millimeter
* Micro switches
* Micro mechined inductors
* Capacitors
* Antennas
* Resonators
* Filters

RF MEMS Application:-

* Electronics (77GHz anti-collision radar, on board GPS)
* RFID (TAGS) – Sensors
* Handsets } Mobile comm.
* Base station }
* Radar system
* ~~S~~ satellite communication
* Adjustable antenna
* LAN'S

Available MEMS Products include:-

* Micro sensors (acoustic wave, biomedical, chemical, inertia, optical, pressure, radiation, thermal, etc)

Mechanical to Electrical

Sensors

Sensors is a device that detects and responds to some type of input from the physical environment. The specific input could be light, heat, motion, moisture, pressure, or any one of a great number of other environmental phenomena. The O/P is generally a signal that is converted to human-readable display

* Micro-actuators (valves, pumps and microfluidics, rotary motor)

Electrical to Mechanical

Actuators

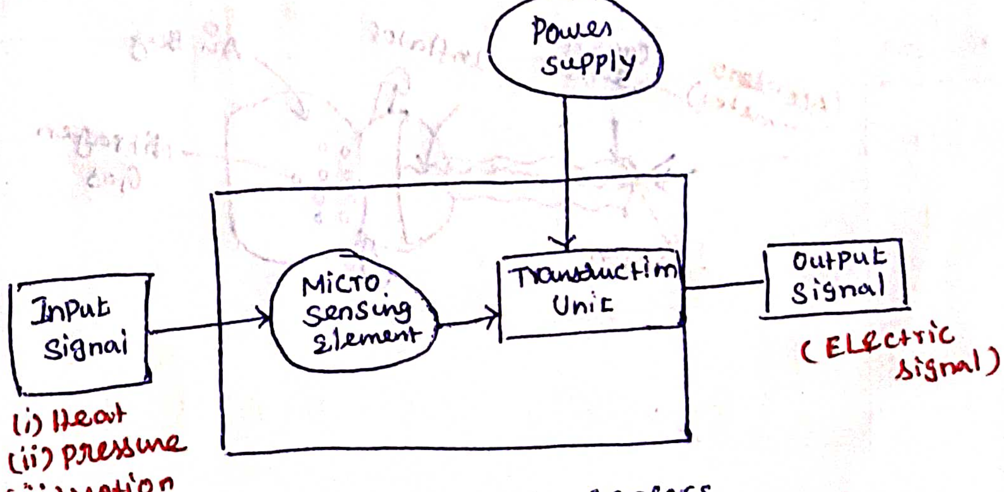
Actuators is something that converts energy into motion. It also can be used to apply a force. An actuator typically is a mechanical device that takes energy.

* Read/write heads in computer storage systems.
* Inkjet printer heads.
* Micro device components (Eg:- Toys, micro surgical and mobile telecom equipment, etc)

MEMS Products

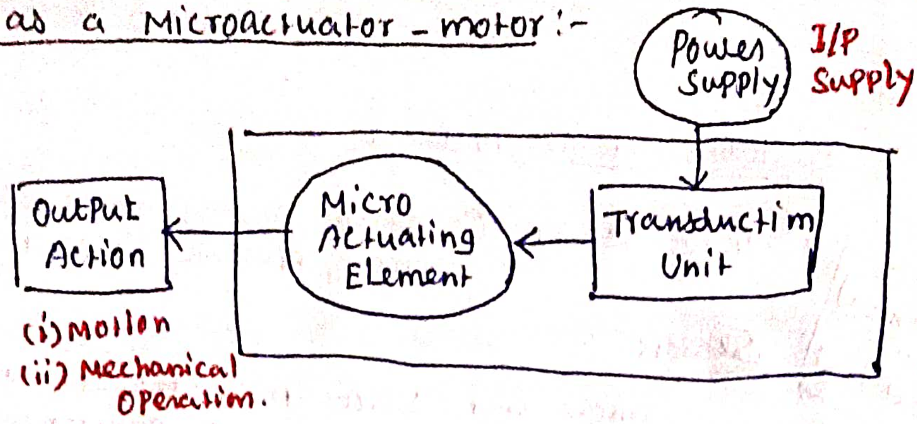
1) MEMS as a Microsensor
2) MEMS as a Micro actuator - Motor
3) Components of Micro system

(i) MEMS as a Micro sensor:-

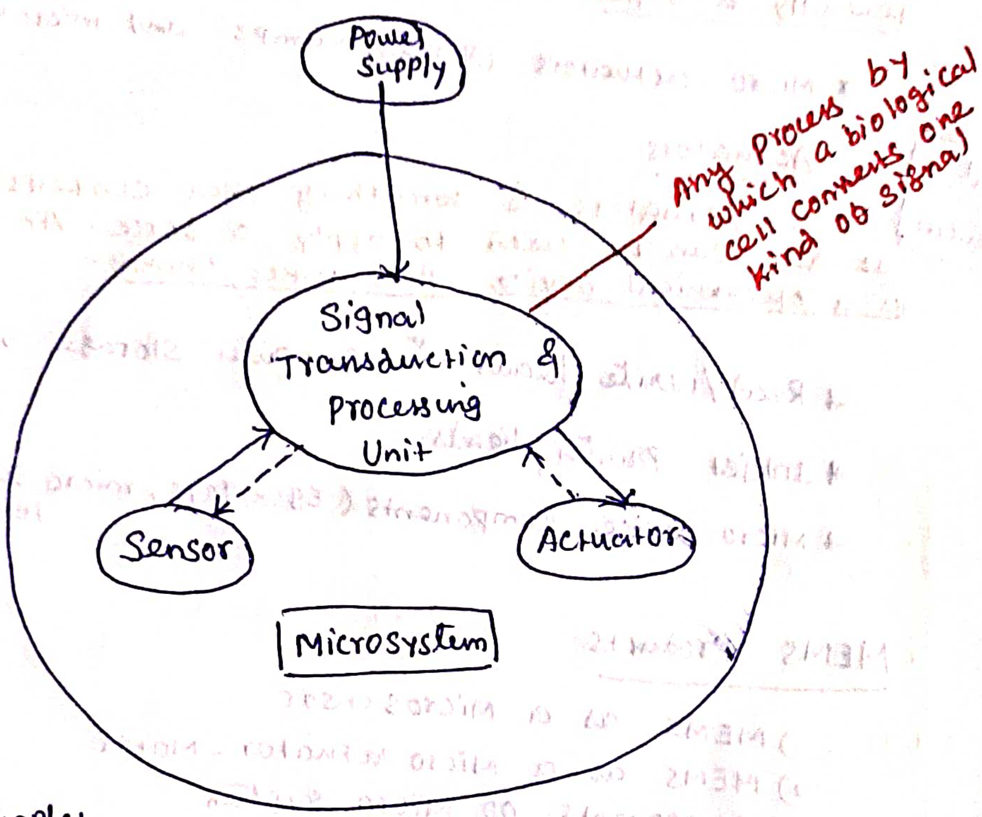


Micro - Pressure sensors

(ii) MEMS as a Microactuator - motor :-

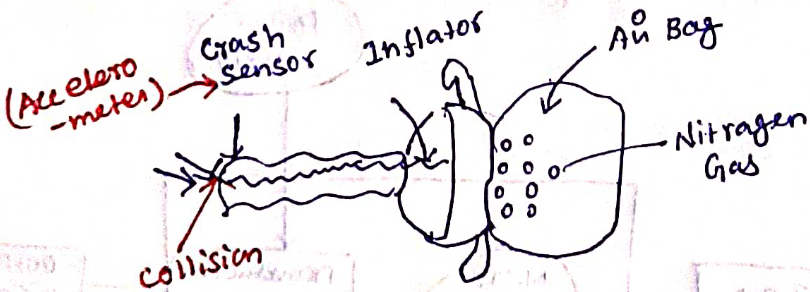


(iii) Components of Microsystems



Examples

1) Air Bag deployment system



Commercial MEMS and Microsystems Products

Micro Sensors

1) Acoustic wave sensors
2) Biomedical and biosensors
3) Chemical sensors
4) Optical sensors
5) Pressure sensors
6) Stress sensors
7) Thermal sensors

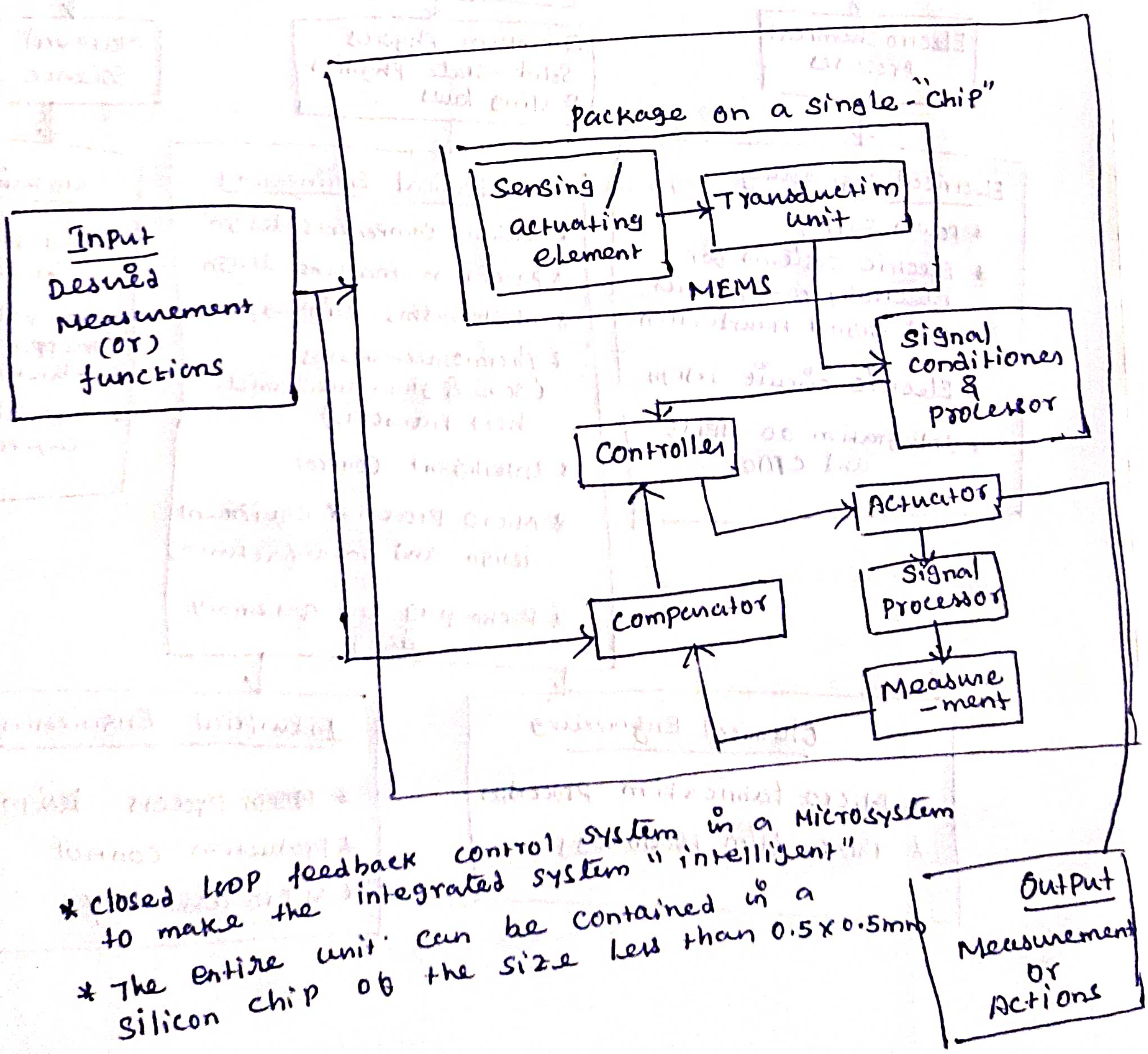
Micro Actuators

1) Grippers
2) Motors
3) Relay and switches
4) Valves and pumps
5) Optical equipment

Microsystems = sensors + actuators + signal transduction

Ex:- (i) Microfluidics
(ii) Microaccelerometers

Intelligent Microsystems:-



* closed loop feedback control system in a Microsystem to make the integrated system "intelligent"
* The entire unit can be contained in a silicon chip of the size less than 0.5×0.5mm

Evolution of Microfabrication :-

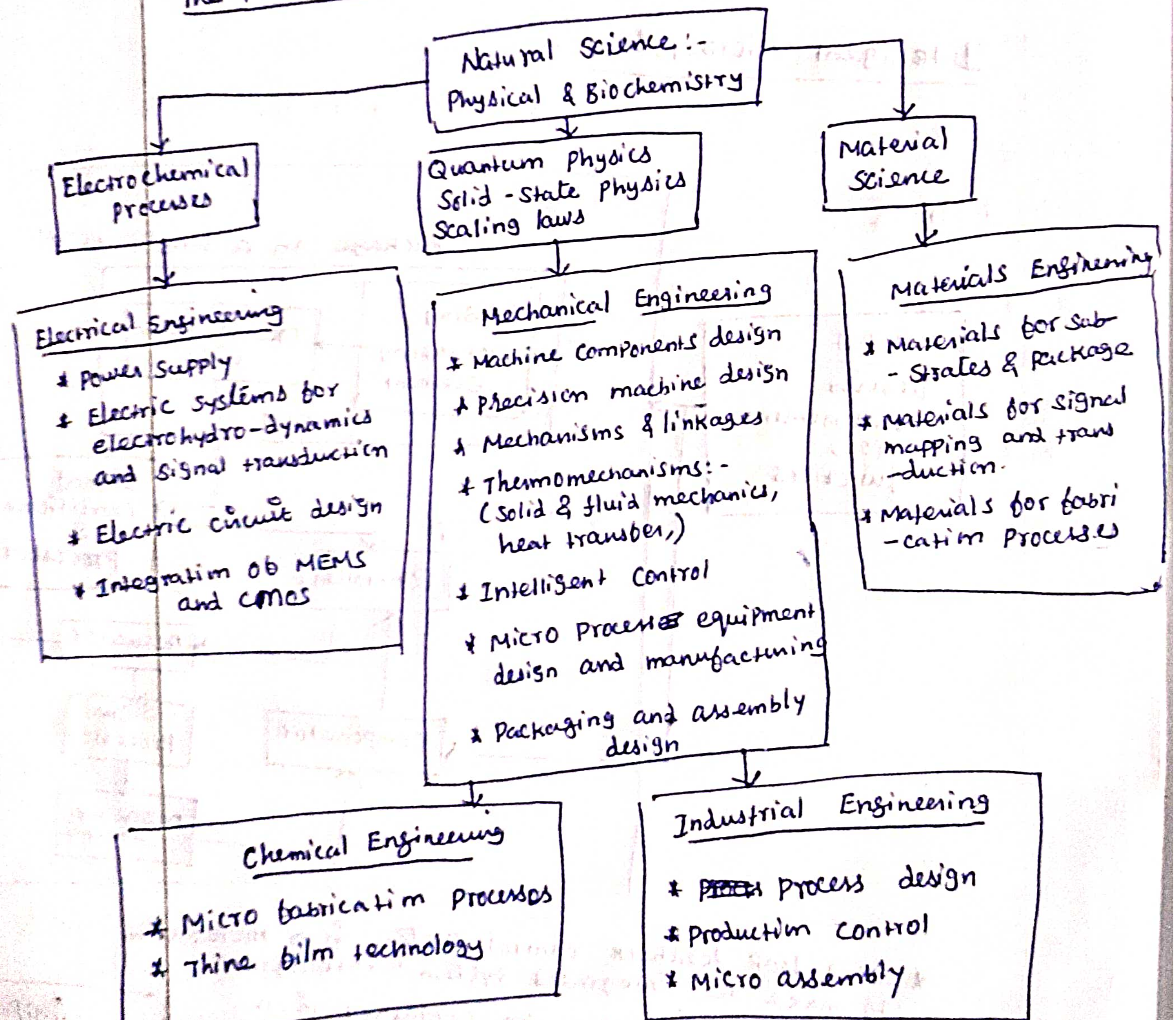
* There is no machine tool with today's technology can produce any device or MEMS component of the size in the micrometer scale (or in mm sizes)

* The complex geometry of these minute MEMS components can only be produced by various Physical - Chemical Processes - the microfabrication techniques originally developed for producing integrated circuit (IC) components.

* Significant technological development towards miniaturization was initiated
    (i) Transistors in 1947
    (ii) Integrated circuit (IC) in 1955

* The invention of transistors is thus regarded as the beginning of the 3rd Industrial Revolution in human civilization.

The Multi-disciplinary Nature of Microsystems Engineering :-



Advantages & Disadvantages :-

* Minimize energy and Materials.
* Improved reproducibility.
* Improved accuracy and reliability.
* Increased Selectivity and Sensitivity.
* Farm establishment requires huge investments.
* Micro-Components are costly compared to macro component.
* Design includes very much complex Procedures.

Materials for MEMS and Microsystems :-

* Many Micro system use Micro electronics materials such as Silicon & gallium arsenide (GaAs) for sensing & actuating element

* We maintained that the current technologies used in Producing MEMS and Microsystems.

* Design of Microsystems and their Packaging, however, is significantly different from that for Microelectronics. Many microsystems use micro electronics materials such as silicon and gallium arsenide (GaAs) for the sensing (or) actuating elements.

Reasons
1) Dimensionally Stable
2) well established fabricating & Packaging technique

* Materials are chosen mainly for MEMS and micro system Products such as quartz and Pyrex, Polymers and plastics and ceramics.

(i) substrates :- Flat Macroscopic object on which Microfabrication.
(ii) wafer :- substrates & a single crystal cut in slices from a larger Piece call a wafer.

Substrates and wafers :-

* The frequently used term substrate in microelectronics means a flat macroscopic object on which microfabrication Processes takes Place

* Substrates in microsystems, however, are somewhat different.

* Substrates in microsystem: There are two types of substrates materials used in microsystem
    (i) Active Substrates Materials
    (ii) Passive Substrates Materials

* Presents a group of materials that are classified as electric insulators, semiconductors, and conductors.

Some Reference to have electrical resistivity ρ in range
(i) insulation of $\rho > 10^{8}\ \Omega\text{-cm}$
(ii) Semiconductors with $10^{-3}\ \Omega\text{-cm} < \rho < 10^{8}\ \Omega\text{-cm}$
(iii) conductors with $\rho < 10^{-3}\ \Omega\text{-cm}$

* Substrate materials used in MEMS such as silicon (Si), germanium (Ge), and gallium arsenide (GaAs) all fall in the category of Semi-conductors

Typical electrical resistivity of insulators, semiconductors and conductors

Materials	Approximate electrical resistivity ρ_r Ω-cm	Classification
Silver (Ag)	10^{-6}	
Copper (Cu)	10^{-58}	Conductors
Aluminum (Al)	10^{-56}	
Platinum (Pt)	10^{-5}	
Germanium (GE)	$10^{-3} - 10^{15}$	
Silicon (Si)	$10^{-3} - 10^{45}$	Semiconductors
Gallium arsenide (GaAs)	$10^{-3} - 10^{8}$	
Gallium phosphide (GaP)	$10^{-2} - 10^{65}$	
Oxide	10^{9}	
Glass	$10^{10.5}$	
Nickel (Pure)	10^{13}	Insulators
Diamond	10^{14}	
Quartz (fused)	10^{18}	

* They are at the borderline between conductors and insulators so they can be made either a conductor or an isulator as needed.
  - → can be converted to a conducting material by doping (P (or) N- Type)
  - → The fabrication processes (eg. etching) and the required equipment have already been developed for these materials.

Chapter 7 Materials for MEMS and Microsystems

7.1 Introduction

- Many Microsystems use microelectronics materials such as silicon, and gallium arsenide (GaAs, 砷化鎵) for the sensing and actuating elements.
  - Reasons: (1) dimensionally stable;
    (2) well-established fabricating and packaging techniques.

- However, there are other materials used for MEMS and Microsystems products:
  - Such as quartz and Pyrex (派萊克斯耐熱玻璃), polymers and plastics, and ceramics. (not common in microelectronics)

7.2 Substrates and Wafers

- Substrate (基底):
  - In microelectronics, substrate is a flat macroscopic object on which microfabrication processes take place [Ruska, 1987].
  - In microsystems, a substrate serves an additional purpose:
    - Act as signal transducer besides supporting other transducers that convert mechanical actions to electrical outputs or vice versa.

- Wafer (晶片, 晶圓):
  - In semiconductors, the substrate is a single crystal cut in slices from a larger piece call a wafer (which can be of silicon or other single crystalline materials such as quartz or gallium arsenide).
  - In microsystems, there are two types of substrate materials:
    1. Active substrate material.
    2. Passive substrate material.

- Material classifications:
  - Insulators: electric resistivity $\rho > 10^8$ Ω-cm
  - Semiconductors: $10^{-3} < \rho < 10^8$ Ω-cm
  - Conductors: $\rho < 10^{-3}$ Ω-cm

Table 7.1 | Typical electrical resistivity of insulators, semiconductors, and conductors

Materials	Approximate electrical resistivity ρ, Ω-cm	Classification
Silver (Ag)	10^{-6}	Conductors
Copper (Cu)	$10^{-5.8}$	
Aluminum (Al)	$10^{-5.5}$	
Platinum (Pt)	10^{-5}	
Germanium (GE)	10^{-3}–$10^{1.5}$	Semiconductors
Silicon (Si)	10^{-3}–$10^{4.5}$	
Gallium arsenide (GaAs)	10^{-3}–10^{8}	
Gallium phosphide (GaP)	10^{-2}–$10^{6.5}$	
Oxide	10^{9}	Insulators
Glass	$10^{10.5}$	
Nickel (pure)	10^{13}	
Diamond	10^{14}	
Quartz (fused)	10^{18}	

- In MEMS, common substrate materials (silicon Si, germanium Ge 鍺, gallium arsenide GaAs) all fall in the category of semiconductors. Why?
  - They are at the borderline between conductors and insulators, so they can be made either a conductor or an insulator as needed.
    → Can be converted to a conducting material by doping (p- or n-type).
  - The fabrication processes (e.g., etching) and the required equipment have already been developed for these materials.

7.3 Active Substrate Materials

- Active substrate materials are primarily used for sensors and actuators in Microsystems (Fig. 1.5).
  - Typical materials: Si, GaAs, Ge, and quartz. (silicon, Gallium arsenide, Germanium) (All except quartz are classified as semiconductors in Table 7.1)
  - Have a cubic crystal lattice with tetrahedral (四面體的) atomic bond.
  - Reason for active substrate materials: dimensional stability
    Not sensitive → Insensitive to environmental conditions.
    → A critical requirement for sensors and actuators with high precision.
  - Each atom carries 4 electrons in the outer orbit, and shares these 4 electrons with its 4 neighbors.

7.4 Silicon as A substrate Material

7.4.1 The Ideal Substrate for MEMS

- Single-crystal silicon is the most widely used substrate material for MEMS and microsystem. The reasons are:
  1. (a) Mechanically stable; (b) can be integrated with electronics for signal transduction on the same substrate.
  2. An ideal structural material because of high Young's modulus (which can better maintain a linear relationship between applied load and the induced deformation) and light weight.
     - About the same as steel (about 2×10^5 MPa)
     - As light as aluminum with a mass density of about 2.3 g/cm^3.
  3. High melting point at 1400℃
     - About twice as high as that of aluminum.
     - Dimensionally stable.
  4. Low thermal expansion coefficient
     - About 8 times smaller than that of steel.
     - More than 10 times smaller than that of aluminum.
  5. (a) Show virtually no mechanical hysteresis (遲滯).

     → An ideal candidate material for sensors and actuators.

     (b) Extremely flat and accept coatings and additional thin-film layers for building microstructures and conducting electricity.
  6. Treatment and fabrication processes for silicon substrate are well established and documented.

7.4.2 Single Crystal Silicon and Wafer

- The Czochralski (CZ) method: is the most popular one to produce pure silicon crystal. (Fig. 7.1)
  - The raw silicon in the form of quartzite (石英岩) are melted in a quartz crucible (坩堝, 熔爐之底部) with carbon (coal, coke, wood chips, etc.), which is placed in a furnace.

    $$SiC + SiO_2 \rightarrow Si + CO + SiO$$
  - A "seed" crystal is brought into contact with the molten silicon to form a larger crystal (a large bologna-shaped boule [人造寶石]).
  - The silicon boule is then ground to a perfect circle, then sliced to form thin disks, which are then chemically-lap (磨平) polished for finishing.

Figure 7.1 | The Czochralski method for growing single crystals (Ruska [1987].)

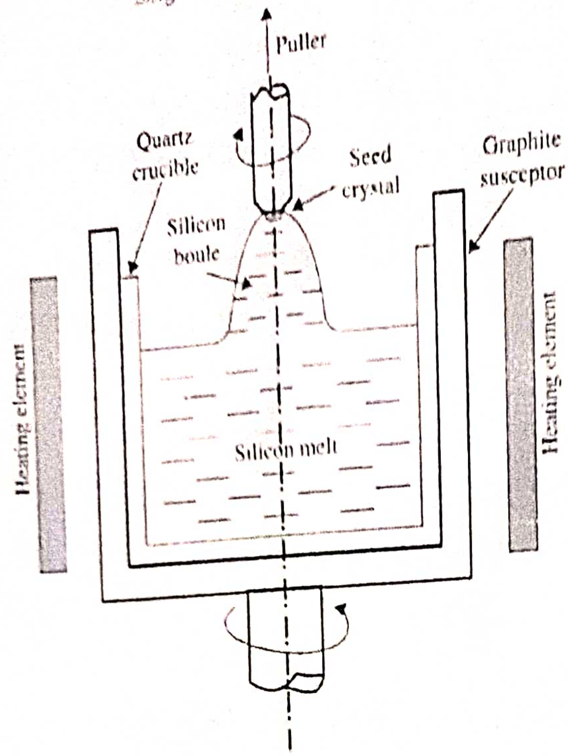
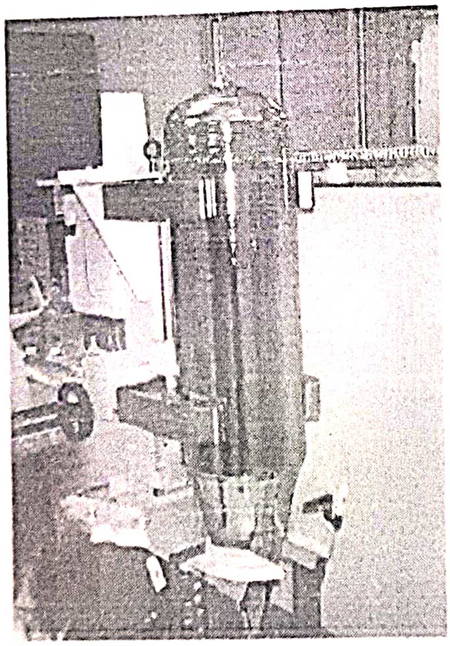


Figure 7.2 | A 300-mm single-crystal silicon boule cooling on a material-handling device.



(Courtesy of MEMC Electronic Materials Inc., St. Peters, Missouri.)

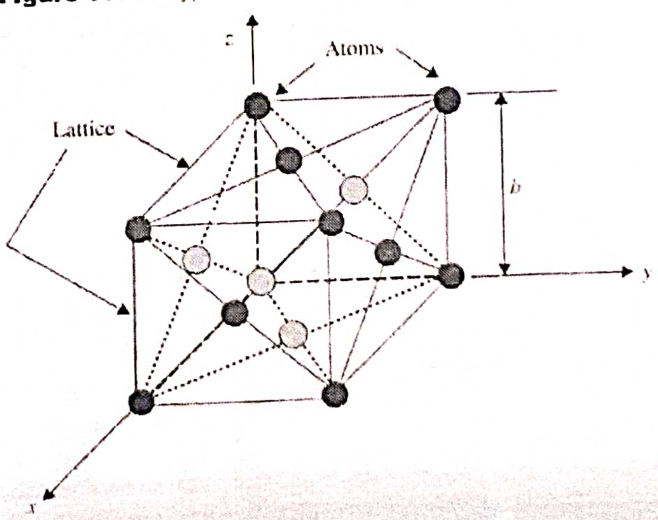
- Wafer sizes:
  - 100 mm (4 in) diameter × 500 μm thick
  - 150 mm (6 in) diameter × 750 μm thick
  - 200 mm (8 in) diameter × 1mm thick
  - 300 mm (12 in) diameter × 750 μm thick (tentative)

- Silicon substrates often are expected to carry electric charges.
  - Require p or n doping of the wafers either by ion implantation or by diffusion (see Sec. 3.5 and Chapter 8).
  - n-type dopants: phosphorus [P, 磷], arsenic [As, 砷], and antimony[Sb, 銻]
  - p-type dopants: boron [B, 硼]

7.4.3 Crystal Structural

- Silicon: has basically a face-centered cubic (FCC) unit cell, called a *lattice* (as shown in Fig. 7.4).
  - Lattice constant b=0.543 nm.
  - Crystal structure of silicon: more complex
    → two penetrating face-centered cubic crystals, as shown in Fig. 4.4.
    → 4 additional atoms in the interior of the FCC.
    → 18 atoms in a unit cell.
    → spacing between adjacent atoms in the diamond subcell: 0.235 nm.
  - Asymmetrical and nonuniform lattice distance: exhibits anisotropic (非等相性的) thermophysical and mechanical characteristics.

Figure 7.4 I A typical face-center-cubic unit cell.



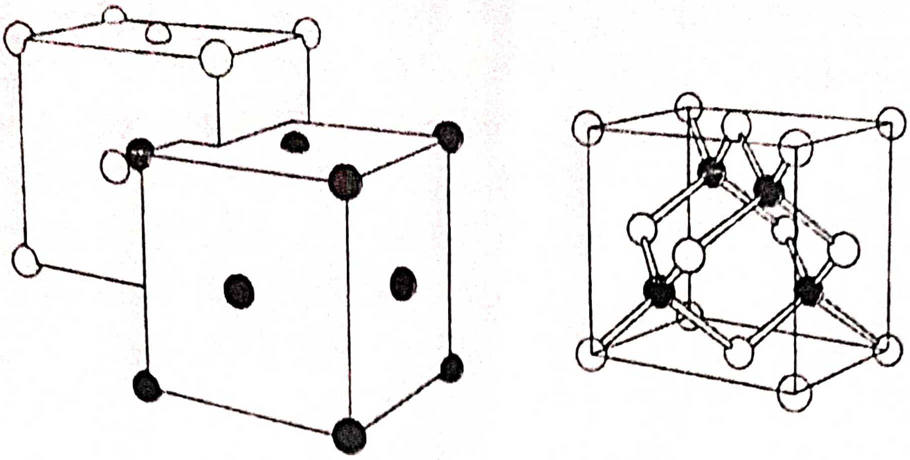


Figure 4.4 The diamond-type lattice can be constructed from two interpenetrating face-centered cubic unit cells. Si forms four covalent bonds, making tetrahedrons.

- Crystal structure of GaAs:

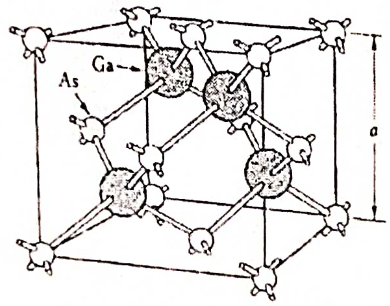


圖 4 1 砷化鎵的結晶結構

7.4.4 The Miller Indices

- Because of the skew (歪曲的) distribution of atoms in a silicon crystal, it is important to designate (指定) the principal orientations as well as planes in the crystal.

- Miller Indices:
  - ➢ A plane that intercepts x, y, and z axes at a, b, and c, can be expressed as:

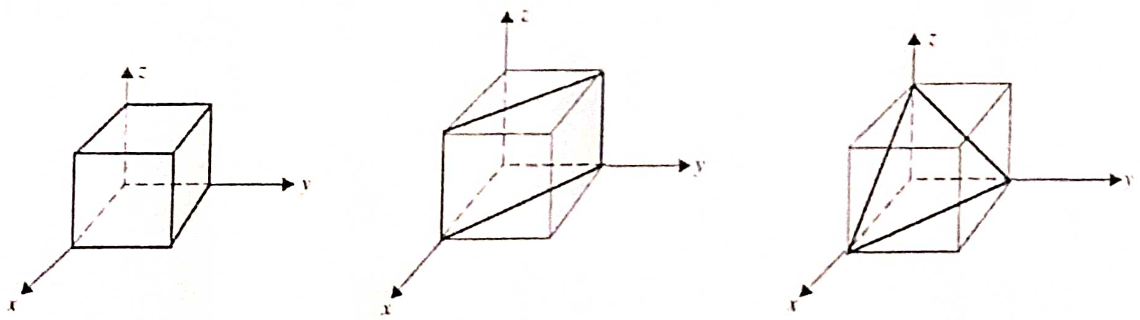
$$\frac{x}{a}+\frac{y}{b}+\frac{z}{c}=1 \qquad (7.1)$$

  - ➢ Equation (7.1) can be rewritten as:

$$hx+ky+mz=1$$

    where h=1/a, k=1/b, and m=1/c.
  - ➢ (hkm): designate the plane, and <hkm>: designate the direction normal to the plane.
  - ➢ Examples:

Figure 7.8 | Designation of the planes of a cubic crystal.



(a) Normal planes (b) Diagonal plane (c) Inclined plane

We can designate various planes in Figure 7.8 by using Equations (7.1) and (7.2) as follows:

Top face in Figure 7.8a:	(001)
Right face in Figure 7.8a:	(010)
Front face in Figure 7.8a:	(100)
Diagonal face in Figure 7.8b:	(110)
Inclined face in Figure 7.8c:	(111)

Figure 7.9 | Silicon crystal structure and planes and orientations.

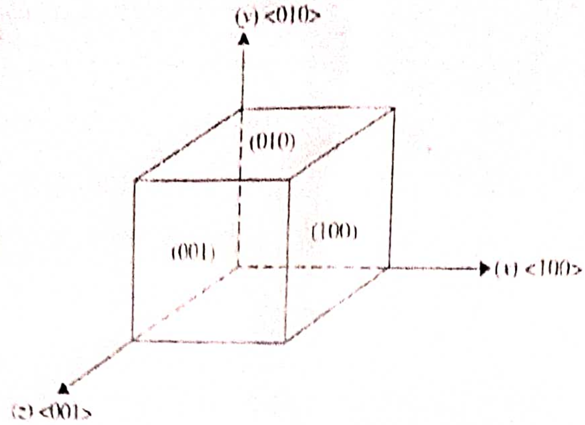
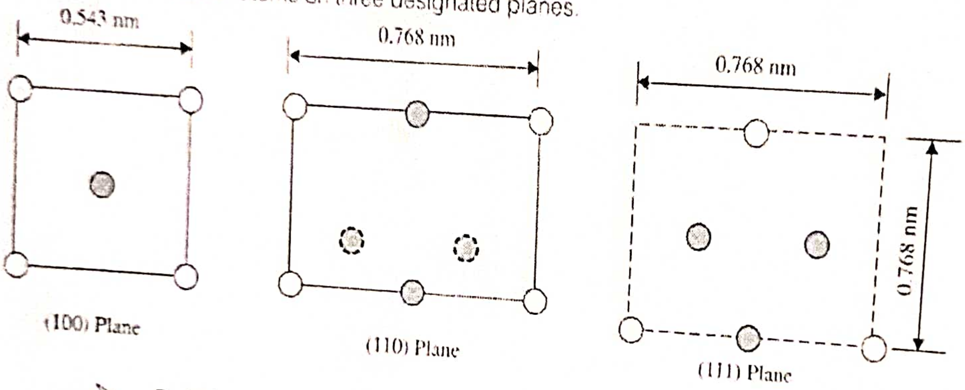


Figure 7.10 | Silicon atoms on three designated planes.



➢ In Fig. 7.10,

- The lattice distances between adjacent atoms are shortest on (111) plane.
- These shortest lattice distance makes the attractive forces between atoms stronger on (111) than those on the (100) and (110) planes.
- On the (111) plane, the growth of crystal is the slowest, and the fabrication processes will proceed slowest.

- Primary flats and secondary flats are used to indicate the crystal orientation and dopant type of the wafers.

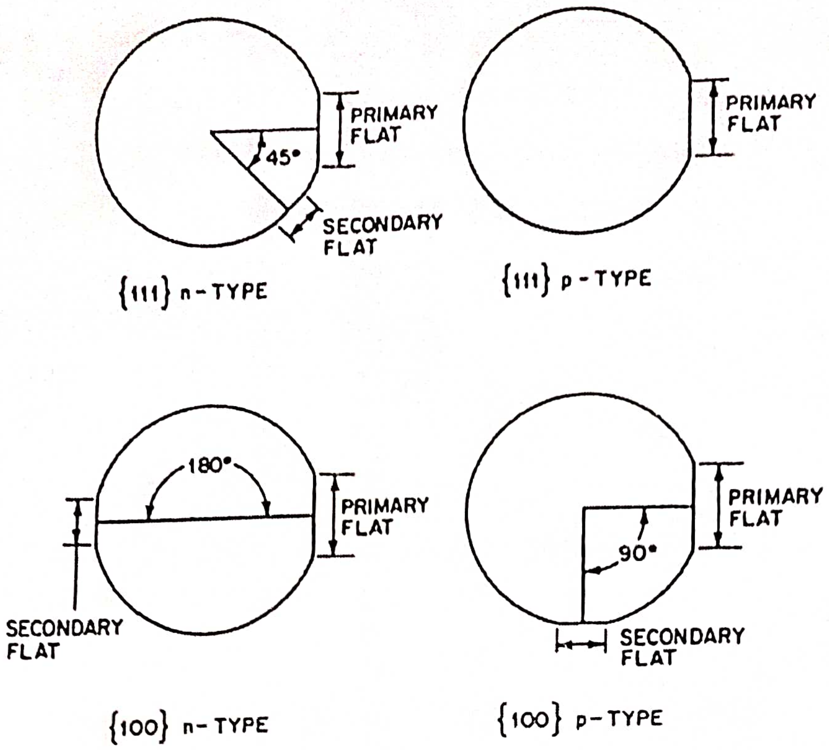


Figure 4.5 Primary and secondary flats on silicon wafers.

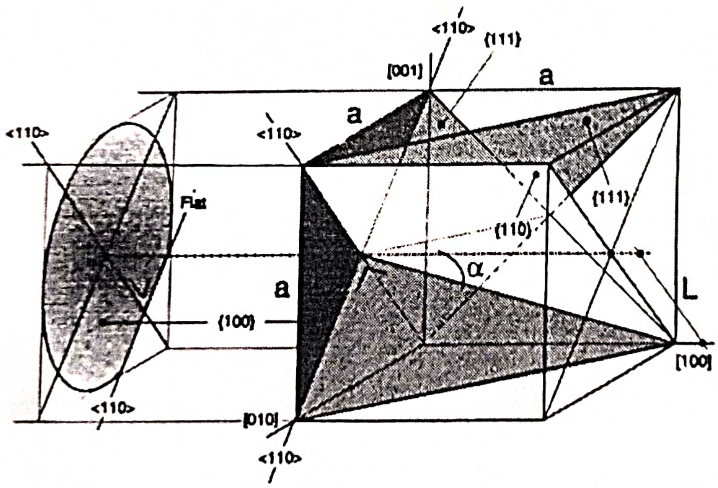


Figure 4.6 (100) silicon wafer with reference to the unity cube and its relevant planes. (From E. Peeters, "Process Development for 3D Silicon Microstructures, with Application to Mechanical Sensor Design," KUL, Belgium, 1994.[42] Reprinted with permission.) (Madou, 1997)

7.4.5 Mechanical Properties of Silicon

- Silicon, as the material of 3-D structures, needs to withstand often-severe mechanical and thermal loads, in addition to accommodating electrical instruments.

- Silicon is an ideal sensing and actuating material because
  1. It is an elastic material with no plasticity (塑性) or creep (潛變，金屬等逐漸變形) below 800℃.
  2. Show virtually no fatigue (疲乏) failure.

- Disadvantages:
  1. brittle (易碎的,脆的)
  2. weak resistance to impact loads
  3. anisotropic (非等向性的), which makes stress analysis of the structures tedious.

- Young's moduli and shear moduli in three directions:

Table 7.2 | The diverse Young's moduli and shear moduli of elasticity of silicon crystals

Miller index for orientation	Young's modulus E, GPa	Shear modulus G, GPa
<100>	129.5	79.0
<110>	168.0	61.7
<111>	186.5	57.5

- Bulk material properties of silicon, silicon compounds, and other active substrate materials:

Table 7.3 | Mechanical and thermophysical properties of MEMS materials*

Material	σ_y, 10^9 N/m²	E, 10^{11} N/m²	ρ, g/cm³	c, J/g-°C	k, W/cm-°C	α, 10^{-6}/°C	T_M, °C
Si	7.00	1.90	2.30	0.70	1.57	2.33	1400
SiC	21.00	7.00	3.20	0.67	3.50	3.30	2300
Si_3N_4	14.00	3.85	3.10	0.69	0.19	0.80	1930
SiO_2	8.40	0.73	2.27	1.00	0.014	0.50	1700
Aluminum	0.17	0.70	2.70	0.942	2.36	25	660
Stainless steel	2.10	2.00	7.90	0.47	0.329	17.30	1500
Copper	0.07	0.11	8.9	0.386	3.93	16.56	1080
GaAs	2.70	0.75	5.30	0.35	0.50	6.86	1238
Ge		1.03	5.32	0.31	0.60	5.80	937
Quartz	0.5-0.7	0.76-0.97	2.66	0.82-1.20	0.067 0.12	7.10	1710

*Principal source for semiconductor material properties: *Fundamentals of Microfabrication*, Marc Madou, CRC Press, 1997

Legend: σ_y = yield strength, E = Young's modulus, ρ = mass density, c = specific heat, k = thermal conductivity, α = coefficient of thermal expansion, T_M = melting point

7.5 Silicon Compounds

- 3 often-used silicon compounds:
  1. Silicon dioxide (SiO_2)
  2. Silicon Carbide (SiC)
  3. Silicon Nitride (Si_3N_4)

7.5.1 Silicon Dioxide (SiO_2)

- Three principal uses of SiO_2:
  1. as a thermal and electric insulator (see Table 7.1);
  2. as a mask (遮蓋物) in the etching of silicon substrates;
     ($\because SiO_2$ has much stronger resistance to most etchants than silicon)
  3. as a sacrificial layer (犧牲層) in the surface micromachining.

- Properties:

Table 7.5 | Properties of silicon dioxide

Properties	Values
Density, g/cm^3	2.27
Resistivity, Ω-cm	$\geq 10^{16}$
Relative permittivity	3.9
Melting point, °C	~1700
Specific heat, J/g-°C	1.0
Thermal conductivity, W/cm-°C	0.014
Coefficient of thermal expansion, ppm/°C	0.5

Source: Ruska [1987]

- Oxidation: by heating silicon in an oxidant (e.g., O_2) with or without steam.
  (a) Dry oxidation:
  $$Si + O_2 \rightarrow SiO_2$$
  (b) Wet oxidation in steam:
  $$Si + 2H_2O \rightarrow SiO_2 + 2H_2$$

- Oxidation is effectively a diffusion process (see Chapter 3). Diffusivity of SiO_2 at 900℃ in dry oxidation:
  (a) 4×10^{-19} cm^2/s for arsenic(砷, As)-doped silicon (n-type);
  (b) 3×10^{-19} cm^2/s for boron(硼, B)-doped silicon (p-type);

Note: Steam would accelerate the oxidation process.

7.5.2 Silicon Carbide (SC)

- Properties and usages:
  1. dimensional and chemical stability at high temperature
     (a) strong resistance to oxidation at very high temperature
     (b) deposited over MEMS components to protect them from extreme temperature
  2. The thin SiC film can be patterned by dry etching with aluminum masks, and can be further used as passivation layer (protective layer) in micromachining for the underlying silicon layer.
     (∵ SiC can resist common etchants such as KOH and HF.)

- SiC: a by-product (副產品) in producing single crystal silicon boule (人造寶石).
  - Intense heating of the carbon raw materials (coal 煤, coke 焦煤, wood chips, etc.) would results in SiC sinking to the bottom of the crucible (坩堝).

- The SiC film: produced by various deposition techniques.
  - Table 7.3 lists some thermophysical properties.

7.5.3 Silicon Nitride (Si_3N_4)

- Superior properties attractive for MEMS:
  - An excellent barrier to diffusion of water and ions (e.g., sodium 鈉)
  - Ultrastrong resistance to oxidation and many etchants
    → Suitable for masks for deep etching.

- Applications:
  - Optical waveguides
  - Encapsulants (膠囊密封藥劑) to prevent diffusion of water and other toxic fluid into the substrate.
  - High-strength electric insulators and ion implantation masks.

- Production Processes:
  - Produced from silicon containing gases and NH_3:

$$3SiCl_2H_2 + 4NH_3 \rightarrow Si_3N_4 + 6HCl + 6H_2 \quad (7.5)$$

  - Can be produced by both LPCVD (low pressure chemical vapor deposition) and PECVD (plasma-enhanced chemical vapor deposition) processes. (chap8)
    Note: plasma - 電漿 (原子核與電子分離的氣體狀態)
  - Properties: listed in Tables 7.3 and 7.6.

Table 7.6 | Selected properties of silicon nitride

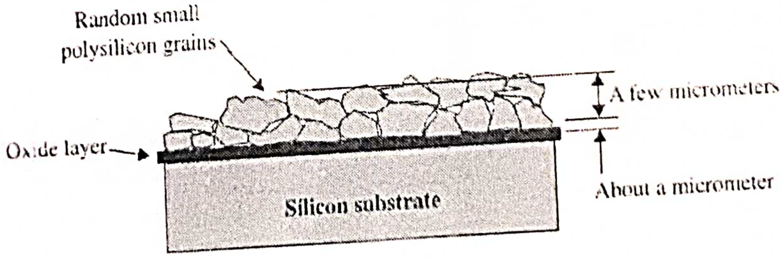
Properties	LPCVD	PECVD
Deposition temperature, °C	700-800	250-350
Density, g/cm^3	2.9-3.2	2.4-2.8
Film quality	Excellent	Poor
Relative permittivity	6-7	6-9
Resistivity, Ω-cm	10^{16}	10^{6}-10^{15}
Refractive index	2.01	1.8-2.5
Atom % H	4-8	20-25
Etch rate in concentrated HF	200 Å/min	
Etch rate in boiling HF	5-10 Å/min	
Poisson's ratio	0.27	
Young's modulus, GPa	385	
Coefficient of thermal expansion, ppm/°C	1.6	

Source. Madou [1997].

7.5.4 Polycrystalline Silicon

- Polysilicon is a principal material in surface micromachining (see Chap.9).

Figure 7.12 | Polysilicon deposits on a silicon substrate.



- Production process:
  - LPCVD is frequently used for depositing polycrystalline silicon onto silicon.
    → Temperature: 600 to 650℃

- Applications and properties:
  - In IC industry: resistors, gates for transistors, thin-film transistors, etc.
  - Highly doped polysilicon can reduce the resistivity of polysilicon to produce conductors and control switches.
    → Ideal material for microresistors as well as easy ohmic contacts.
  - Polysilicon can be treated as isotropic material in structural and thermal analyses (due to its crystals in random sizes and orientations).
  - Table 7.7: list some key properties of polysilicon and other materials.

Table 7.7 | Comparison of mechanical properties of polysilicon and other materials

Materials	Young's modulus, GPa	Poisson's ratio	Coefficient of thermal expansion, ppm/°C
As substrates:			
Silicon	190	0.23	2.6
Alumina	415		8.7
Silica	73	0.17	0.4
As thin films:			
Polysilicon	160	0.23	2.8
Thermal SiO_2	70	0.2	0.35
LPCVD SiO_2	270	0.27	1.6
PECVD SiO_2			2.3
Aluminum	70	0.35	25
Tungsten	410	0.28	4.3
Polymide	3.2	0.42	20–70

Source: Madou [1997]

7.6 Silicon Piezoresistors

- Definition of piezoresistance (壓阻):
  - A change in electric resistance of solids when subjected to stress fields.
- Both p- ad n-type silicon exhibit excellent piezoresistive effect.
- Due to anisotropic in p- and n-type silicon, the relationship between the resistance change and the stress field is more complex:

$$\{\Delta R\} = [\pi]\{\sigma\}$$

where $\{\Delta R\} = \{\Delta R_{xx} \quad \Delta R_{yy} \quad \Delta R_{zz} \quad \Delta R_{xy} \quad \Delta R_{xz} \quad \Delta R_{yz}\}^T$: change of resistance in an infinitesimally small cubic piezoresistive crystal element with corresponding stress components $\{\sigma\} = \{\sigma_{xx} \quad \sigma_{yy} \quad \sigma_{zz} \quad \sigma_{xy} \quad \sigma_{xz} \quad \sigma_{yz}\}^T$, and $[\pi]$: piezoresistive coefficient matrix, which has the form: (7.6)

$$[\pi] = \begin{bmatrix} \pi_{11} & \pi_{12} & \pi_{12} & 0 & 0 & 0 \\ \pi_{12} & \pi_{11} & \pi_{12} & 0 & 0 & 0 \\ \pi_{12} & \pi_{12} & \pi_{11} & 0 & 0 & 0 \\ 0 & 0 & 0 & \pi_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & \pi_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & \pi_{44} \end{bmatrix} \quad (7.7)$$

- That is,

$$\Delta R_{xx} = \pi_{11}\sigma_{xx} + \pi_{12}(\sigma_{yy} + \sigma_{zz})$$
$$\Delta R_{yy} = \pi_{11}\sigma_{yy} + \pi_{12}(\sigma_{xx} + \sigma_{zz})$$
$$\Delta R_{zz} = \pi_{11}\sigma_{zz} + \pi_{12}(\sigma_{xx} + \sigma_{yy})$$
$$\Delta R_{xy} = \pi_{44}\sigma_{xy}$$
$$\Delta R_{xz} = \pi_{44}\sigma_{xz}$$
$$\Delta R_{yz} = \pi_{44}\sigma_{yz}$$

- π_{11} and π_{12} are associated with the normal stress components, whereas π_{44} is related to the shearing stress components.

Figure 7.13 I A silicon piezoresistance subjected to a stress field.

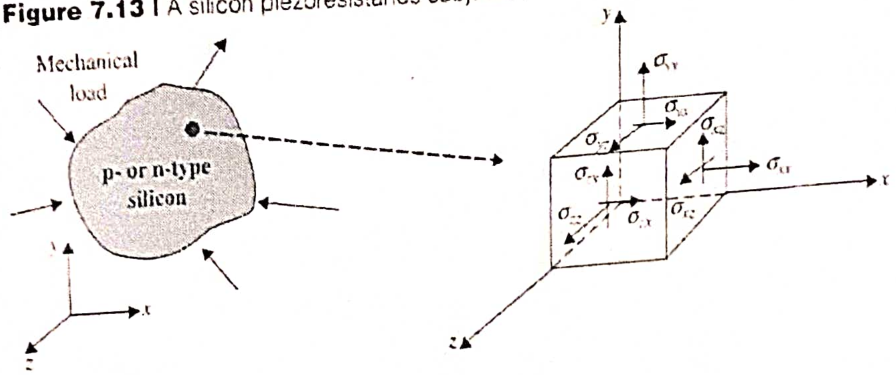


Table 7.8 I Resistivity and piezoresistive coefficients of silicon at room temperature in <100> orientation

Materials	Resistivity, Ω-cm	π_{11}*	π_{12}*	π_{44}*
p silicon	7.8	+6.6	−1.1	+138.1
n silicon	11.7	−102.2	+53.4	−13.6

*In 10^{-12} cm²/dyne or in 10^{-11} m²/N (or Pa⁻¹)

Source: French and Evans [1988]

- In Fig 7.14, The change of electric resistance can be expressed as

$$\frac{\Delta k}{R} = \pi_L\sigma_L + \pi_T\sigma_T \tag{7.8}$$

where π_L and π_T denote the piezoresistive coefficients along the longitudinal and tangential directions, respectively.

Figure 7.14 I Silicon strain gages

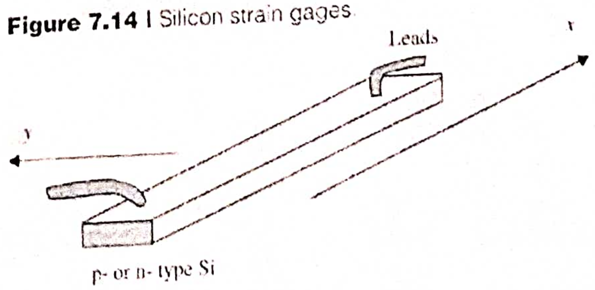


Table 7.9 | Piezoresistive coefficients of p-type silicon piezoresistors in various directions

Crystal planes	Orientation <x>	Orientation <y>	π_L	π_T
(100)	<111>	<211>	$+0.66\pi_{44}$	$-0.33\pi_{44}$
(100)	<110>	<100>	$+0.5\pi_{44}$	-0
(100)	<110>	<110>	$+0.5\pi_{44}$	$-0.5\pi_{44}$
(100)	<100>	<100>	$+0.02\pi_{44}$	$+0.02\pi_{44}$

Source: Brysck et al. [1991].

- Relationship between (π_l, π_t) and (π_{11}, π_{12}, π_{44}) [Senturia, 2001]

$$\pi_l = \pi_{11} - 2(\pi_{11} - \pi_{12} - \pi_{44})\left(l_1^2 m_1^2 + l_1^2 n_1^2 + m_1^2 n_1^2\right) \quad (18.8)$$

and

$$\pi_t = \pi_{12} + (\pi_{11} - \pi_{12} - \pi_{44})\left(l_1^2 l_2^2 + m_1^2 m_2^2 + n_1^2 n_2^2\right) \quad (18.9)$$

where (l_1, m_1, n_1) and (l_2, m_2, n_2) are the sets of direction cosines between the longitudinal resistor direction (subscript 1) and the crystal axis, and between the transverse resistor direction (subscript 2) and the crystal axes.

In many silicon micromachined devices, resistors are oriented along [110] directions in (100) wafers.[4] The longitudinal direction cosines are $(1/\sqrt{2}, 1/\sqrt{2}, 0)$ and the transverse direction cosines are $(-1/\sqrt{2}, 1/\sqrt{2}, 0)$. This results in

$$\pi_{l,110} = \frac{1}{2}(\pi_{11} + \pi_{12} + \pi_{44}) \quad (18.10)$$

and

$$\pi_{t,110} = \frac{1}{2}(\pi_{11} + \pi_{12} - \pi_{44}) \quad (18.11)$$

7.7 Gallium Arsenide (GaAs, 砷化鎵)

- GaAs
  - A compound semiconductor
  - Advantages
    - ➢ A prime candidate material for photonic device due to its high mobility of electrons (7 times higher than silicon, see Table 7.11)
      → easier for electric current to flow in the material
    - ➢ Superior thermal insulator with excellent dimensional stability at high temperature

Table 7.11 | Electron mobility of selected materials at 300 K

Materials	Electron mobility, $m^2/V \cdot s$
Aluminum	0.00435
Copper	0.00136
Silicon	0.145
Gallium arsenide	0.850
Silicon oxide	~0
Silicon nitride	~0

Source: Kwok [1997]

- Disadvantages
  - ➢ More difficult to process than silicon
  - ➢ Low yield strength (one-third of that of silicon)
  - ➢ More expensive than silicon due to its low use
- Comparison of GaAs and silicon

Table 7.12 | A comparison of GaAs and silicon in micromachining

Properties	GaAs	Silicon
Optoelectronics	Very good	Not good
Piezoelectric effect	Yes	No
Piezoelectric coefficient, pN/°C	2.6	NI
Thermal conductivity	Relatively low	Relatively high
Cost	High	Low
Bonding to other substrates	Difficult	Relatively easy
Fracture	Brittle, fragile	Brittle, strong
Operating temperature	High	Low
Optimum operating temp., °C	460	300
Physical stability	Fair	Very good
Hardness, GPa	7	10
Fracture strength, GPa	2.7	6

Source: Madou [1997]

7.8 Quartz (石英)

- Quartz
  - A compound of SiO_2
  - Unit cell in the shape of tetrahedron (四面體)
  - Orientation: (Senturia, 2001)
    - ➢ Not based on miller indices
    - ➢ Some basic orientations, such as *X*-cut and *Z*-cut quartz, refer to the crystalline axes normal to the plane of the wafer.
    - ➢ However, some others, such as *AT*-cut quartz, refer to off-axis orientations that are selected for specific temperature insensitivities of their piezoelectric or mechanical properties.
  - An ideal material for sensor because of its near absolute thermal dimensional

stability

- A desirable material in microfluidics applications in biomedical analyses
  - Inexpensive
  - Work well in electrophoretic (電泳) fluid transportation due to its excellent electric insulation (絕緣) properties
  - Transparent to ultraviolet light which is good for the purpose of species detection
- Hard to machine
  - Could use "diamond cutting" or "ultrasonic cutting"
  - Can be etched chemically by HF/NH_4F into the desired shape
- More dimensionally stable than silicon
- More flexibility in geometry than silicon

Table 7.13 | Some properties of quartz

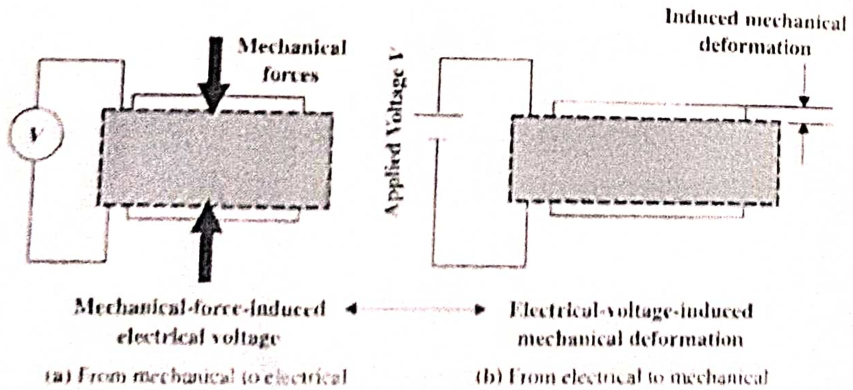
Properties	Value ∥ Z	Value ⊥ Z	Temperature dependency
Thermal conductivity, cal/cm-s°C	29×10^{-3}	16×10^{-3}	↓ with T
Relative permittivity	4.6	4.5	↓ with T
Density, kg/m³	2.66×10^{3}	2.66×10^{3}	
Coefficient of thermal expansion, ppm/°C	7.1	13.2	↑ with T
Electrical resistivity, Ω/cm	0.1×10^{15}	20×10^{15}	↓ with T
Fracture strength, GPa	1.7	1.7	↓ with T
Hardness, GPa	12	12	

Source: Madou [1997]

7.9 Piezoelectric Crystals

- Piezoelectric crystals
  - Piezoelectric effect:
    - Produce a voltage when subjected to an applied force
    - The application of voltage to the crystal can change its shape.

Figure 7.16 | Conversion of mechanical and electrical energies by piezoelectric crystals



(From Kasap [1997].)

- Natural crystals: quartz (石英), tourmaline (電氣石), and sodium (鈉) potassium (鉀) tartrate (酒石酸鹽[酯])
- Synthesized crystals: Rochelle salt, barium titanate, and lead zirconate titanate (PZT)
- Its structure should have no center of symmetry
  - The applied stress will alter the separation between the positive and negative charge sites in an elementary cell, leading to a net polarization at the crystal surface.

    → result in an electric field with voltage potential
- Applications
  - High voltage generation via the application of high compressive stress

    → can be used as an impact detonation (引爆) device.

    → can be used to send signals for depth detection in a sonar (聲納) system
  - In MEMS: used as actuators (see Chapter 2) and dynamic signal transducers for pressure sensors and accelerometers.
  - Used in pumping mechanisms for microfluidic flows (Chapters 5 & 6) as well as for inkjet printer heads.

- Effectiveness of the conversion of mechanical to electrical energy and vice versa can be assessed by the electromechanical conversion factor K:

$$K^2 = \frac{\text{output of mechanical engergy}}{\text{input of electrical engergy}} \quad (7.9a)$$

or

$$K^2 = \frac{\text{output of electrical engergy}}{\text{input of mechanical engergy}} \quad (7.9b)$$

  - The electric field produced by stress

$$V = f\sigma \quad (7.10)$$

    where V: generated electric field in V/m; f: constant coefficient; σ: applied stress in pascals (Pa)
  - The mechanical strain produced by the electric field

$$\varepsilon = dV \quad (7.11)$$

    where ε: induced strain; V: applied electric field in V/m; d: piezoelectric coefficient (see Table 7.14)

  - Relation between f and d:

$$\frac{1}{fd} = E \quad (7.12)$$

where *E*: the Young's modulus

Table 7.14 | Piezoelectric coefficients of selected materials

Piezoelectric crystals	Coefficient *d*, 10^{-12} m/V	Electromechanical conversion factor *K*
Quartz (crystal SiO_2)	2.3	0.1
Barium titanate ($BaTiO_3$)	100–190	0.49
Lead zirconate titanate, PZT ($PbTi_{1-x}Zr_xO_3$)	480	0.72
$PbZrTiO_6$	250	
$PbNb_2O_6$	80	
Rochelle salt ($NaKC_4H_4O_6 \cdot 4H_2O$)	350	0.78
Polyvinylidene fluoride, PVDF	18	

Source: Kasap [1997], Askeland [1994]

7.10 Polymers

- Polymers
  - Include diverse materials such as plastics, adhesives, Plexiglas (普列克斯玻璃: 用以製造飛機座艙罩等的丙烯酸樹脂的商品名), and Lucite (路賽特: 一種透明或半透明的合成樹脂,發螢光,用於反射鏡、飛機窗子等)
  - Become increasingly popular materials for MEMS and Microsystems
  - Examples in MEMS and microsystems:
    - ➢ Plastic cards approximately 150 mm wide containing 1000 microchannels for microfluidic electrophoretic systems by the biomedical industry (Lipman, 1999)
    - ➢ Epoxy resins (環氧樹脂) and adhesives (黏著劑) such as silicone rubber (矽氣橡膠 - 在高溫和低溫下都能保持彈性) used in packing
  - Made up of long chains of organic (有機體[物]的, mainly hydrocarbon) molecules
  - Characteristics:
    - ➢ Low mechanical strength
    - ➢ Low melting point
    - ➢ Poor electric conductivity
  - Thermoplastics and thermosets: 2 groups of common polymers
    - ➢ Thermoplastics: easily formed to the desired shape
    - ➢ Thermosets: have better mechanical strength and temperature resistance up to 350℃

7.10.1 Polymer as Industrial Materials

- Applications:
  - Used as insulators, sheathing ([電纜的]護皮), capacitor films in electric

devices, and die pads in integrated circuits.

- Advantages
  - ➢ Light weight
  - ➢ Ease in processing
  - ➢ Low cost of raw materials and processes for producing polymers
  - ➢ High corrosion resistance
  - ➢ High electrical resistance
  - ➢ High flexibility in structures
  - ➢ High dimensional stability
  - ➢ Great variety

7.10.2 Polymers for MEMS and Microsystems

- Applications:

1. Photoresist (光阻) polymers: used as masks for creating desired patterns on substrates by photolithography (微影).
2. Photoresist polymers: used to produce the prime mold in the LIGA process.
3. Conductive polymers: used as organic substrates.
4. Ferroelectric (鐵電性的) polymers (which behave like piezoelectric crystals): used as a source of actuation in microdevices such as those for micropumping (Sec.5.6.3).
5. Thin Langmuir-Blodgett (LB) film: used for miltilayer microstructures
6. Used as a coating substances for capillary tubes to facilitate electro-osmotic flow in microfluidics (Sec. 3.8.2)
7. Thin polymer films: used as electric insulators in microdevices and asa dielectric substances in microcapacitors.
8. Used for electromagnetic interference (EMI) and radio-frequency interference (RFI, 射頻干擾) shielding (遮蔽) in Microsystems.
9. Used for the encapsulation (密封)of microsensors and packaging of other microsystems.

7.10.3 Conductive Polymers

- For some application, polymers have to be made electrically conductive.
  - By nature, polymers: poor electric conductors (Table 7.15).
  - Polymers can be made electrically conductive by the following 3 methods:

1. Pyrolysis:
   - A pyropolymer based on phthalonitrile resin: by adding an amine (胺－ 氨分子中的氫原子被烷基取代而形成的鹼式化合物) heated above 600℃

Table 7.15 | Electric conductivity of selected materials

Materials	Electric conductivity, S/m*
Conductors:	10^{6}–10^{8}
Copper	10^{4}
Carbon	
Semiconductors:	10^{0}
Germanium	10^{-4}–10^{-2}
Silicon	
Insulators:	10^{-10}–10^{-8}
Glass	10^{-14}–10^{-12}
Nylon	10^{-16}–10^{-14}
SiO_2	10^{-16}–10^{-14}
Polyethylene	

*S/m = siemens per meter. Siemens = Ω^{-1} = $A^2 \cdot s^3/kg \cdot m^3$

2. Doping

   Examples:

   - For polyacetylenes (PA): Dopants such as Br_2, I_2, AsF_5, $HClO_4$, and H_2SO_4 to produce p-type polymers, and sodium naphthalide in tetrahydrofuran (THF, 四氫〔1071〕喃: 一種無色液體,用於製造溶劑、尼龍等) for the n-type polymer.
   - For PPP and PPS: see page 265

3. Insertion of Conductive Fibers (纖維)

   A. Incorporate conductive fillers (e.g., carbon, aluminum flakes, stainless steel, gold, and silver fibers) into both thermosetting and thermoplastic polymer structures.

   B. Other inserts include semiconducting fibers (nanometers in length), e.g., silicon and germanium.

7.10.4 The Langmuir-Blodgett (LB) Film

- LB film
  - made by a special process (LB process) to produce thin polymer films
  - involves spreading volatile solvent (溶劑) over surface-active materials
  - The LB process can produce more than a single monolayer structure (i.e., create a multi-layer structure).

    → regarded as an alternative micromanufacturing technique.

- Applications:

1. Ferroelectric polymer thin films
   - Such as polyvinylidene fluoride (PVDF, 聚偏二乙烯的氟化物)
   - Applications: (a) sound transducers in air and water, (b) tactile (觸覺的)

sensors, (c) biomedical applications (such as I. Tissue-compatible implants, II. cardiopulmonary (心肺的) sensors, and III. implantable transducers and sensors for prosthetics (修復術) and rehabilitation (康復) devices)

- See Table 7.14 for the piezoelectric coefficient of PVDF.

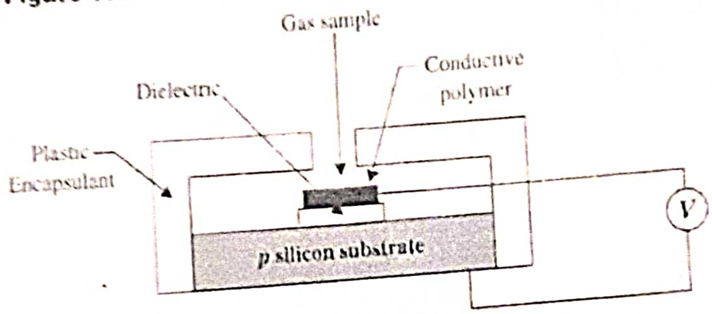
2. Coating materials with controllable optical properties
   - widely used in broadband optical fibers

3. Microsensors

   Principle of Fig. 7.20:

   - The electric conductivity of the polymer sensing element will change when it is exposed to a specific gas.

Figure 7.20 I Microsensor using polymers.



7.11 Packaging Materials

- Distinction between the IC packaging and the microsystems packaging:
  - For IC: to protect from the hostile operating environment.
  - For microsystems: in addition to protection, it is required to be in contact with the media that are sources of action.

- Materials for microsystem packaging:
  - Include those for IC packaging:

    (a) wires made of noble metals at silicon die level,

    (b) metal layers for lead wires,

    (c) solders (焊劑) for die/constraint base attachments, etc.
  - Also include metal and plastics.

- Consider the microsystem packaging in Fig. 7.21:

  (a) Use aluminum or gold metal films as ohmic contacts to the piezoresistors that are diffused in the silicon diaphragm.

(b) Similar materials: used for the lead wires to the interconnects outside the casing.

(c) Casing: made of plastic or stainless steel

(d) Constrain base: made of glass (e.g., Pyrex [派萊克斯耐熱玻璃]) or ceramics (e.g., alumina [明礬])

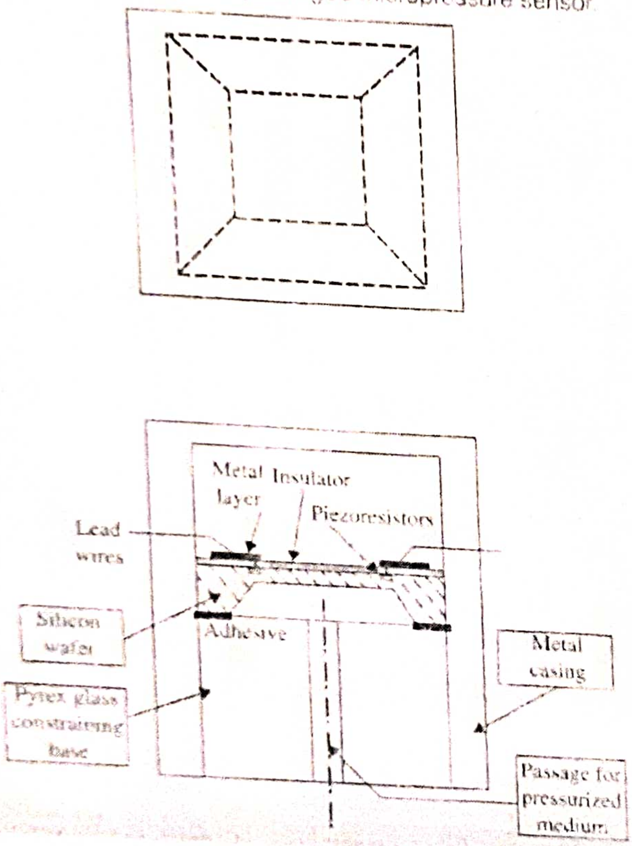
(e) Adhesives that attach the silicon die to the constraint base: can be

i) tin-lead (錫鉛) solder alloys (thin metal layers needs to be sputtered at the joints to facilitate the solderingP;

ii) epoxy resins (環氧樹脂)

iii) or Room-temperature vulcanizing (RTV) silicone rubber.

Figure 7.21 | A typical packaged micropressure sensor



ANNAMALAI UNIVERSITY

ADDITIONAL BOOK

SIGNATURE OF HALL INVIGILATOR

DOPING

* There are three types of engineering materials that we use frequently for electro-mechanical systems.

where

1. Electrical conducting Materials
2. Electrical insulation (or) dielectric Materials
3. Semiconducting Materials

* The classification of these materials is established according to the materials ability to conduct electricity. which is related to the resistance of the materials to the movement of electrons.

* The class of materials that is of particular importance to MEMS and microsystems is semiconductors.

* These materials have some natural electrical conductivity but cannot conduct electricity as well as the conductors. (electrical resistivities reduced to the order of $10^{-3}\Omega$ cm)

* By implantation of certain foreign impurities. The process of turning Semiconducting materials to be electrically conducting is called doping.

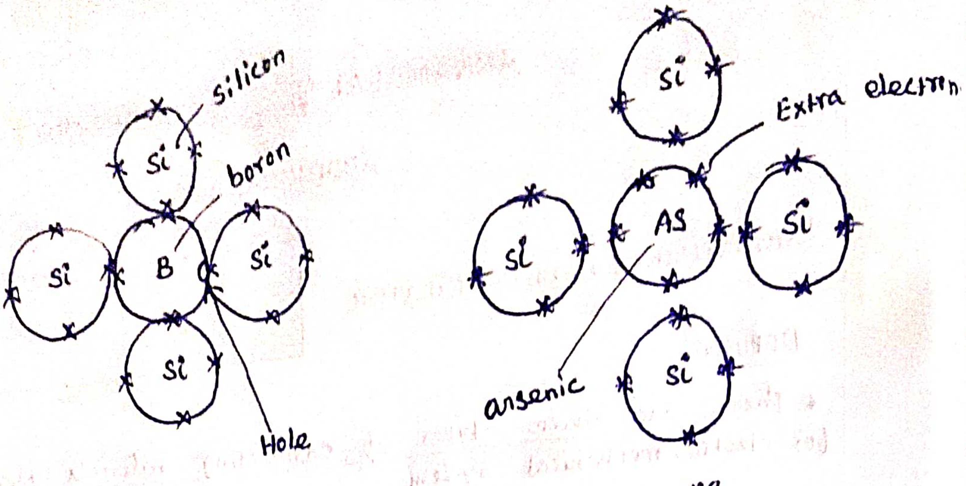
* Doping Patterns control both the intensity and path of electric current flow through the semiconductor Material.

* Microtransistors and microcircuits produced in integrated circuits are formed by using this type of doping process.

* In MEMS and Microsystem, doping of semiconducting materials such as silicon substrates can also alter the material's resistance to chemical or physical etching, which is a common technique. in microfabrication.

* Doping is an essential process to produce P-N junction in microelectronics

* Doping of semiconductors can be achieved by altering the number of electrons in their atoms by implanting foreign atoms with different numbers of electrons.



P-type

N-type

Doping of semiconductors can be achieved by either the diffusion process (or) ion implantation.

OXIDATION – Page No:- 282 / MEMS & Microsystem Design & Manufacture AUR:- Tai-Ran Hsu

* Oxidation is a very important process in both microelectronics and microsystem fabrication. According to size

* There are four types of thin films that are frequently used in microelectronics.

(1) Thermal oxidation for electrical (or) Thermal insulation media.

(2) Dielectric layer for electrical insulation.

(3) Polycrystalline silicon for local electrical conduction.

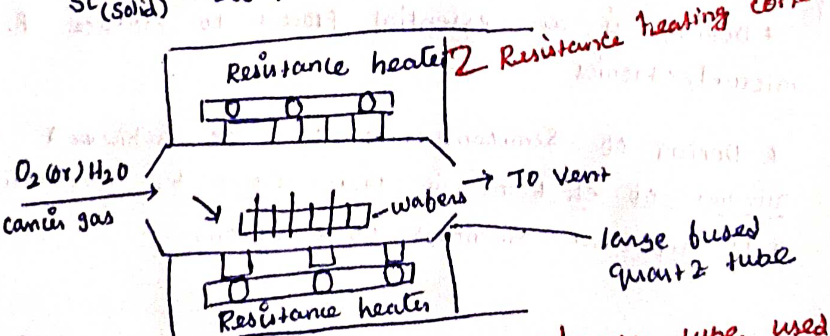
(4) Metal films for electrical contact and junctions.

* All these types of thin films are also widely used in MEMS and microsystems for similar purposes.

* We will focus our attention on the thermal oxidation process commonly used for the production of silicon dioxide films in microsystems.

* The least expensive way to produce SiO_2 film on the silicon substrate is by thermal oxidation. Chemical reactions used in this process are as follows,

$$Si_{(solid)} + O_{2(gas)} \rightarrow SiO_{2(solid)}$$

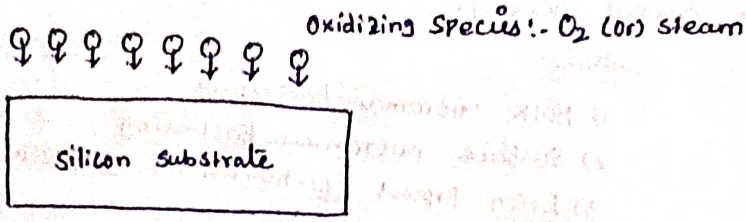


* furnace tube used in industry is order to 30cm Diameter & 3m Length.

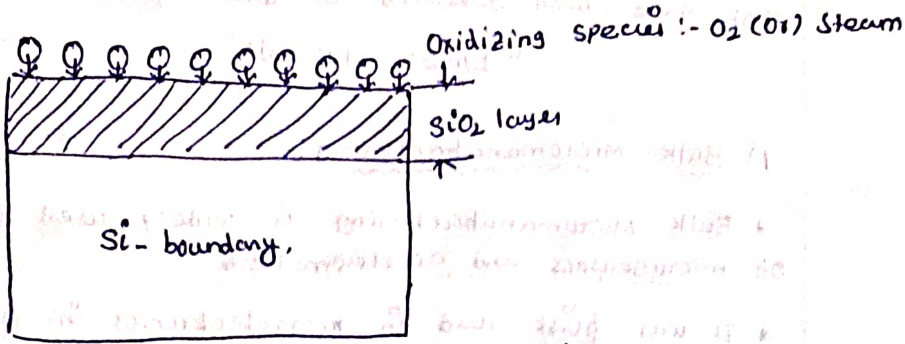
* Temp = 900 to 1200°C

* The timing, temperature and gas flow are strictly controlled in order to thickness of SiO_2 film.

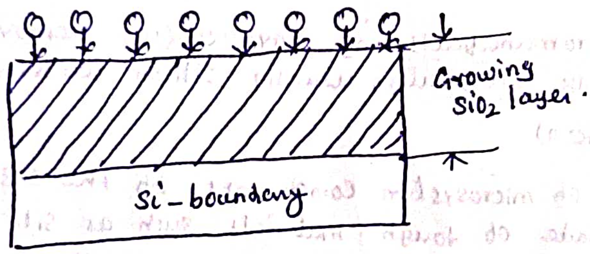
Thermal oxidation step:-



step:-01



step :-02 / Formation of oxide layer.



MICROMANUFACTURING:- (Page NO:- 309)

* For mechanical engineers, a major effort in manufacturing a Product is the proper selection and application of fabrication techniques such as
  - Machining
  - Drilling
  - Milling
  - Forging
  - welding
  - Casting
  - Molding
  - Stamping
  - peening

* we will quickly realize that none of these traditional fabrication techniques can be used in manufacturing MEMS and MICRO SYSTEAM because of the extremely small size of these Products.

* Traditional fabrication techniques, however used in the Packaging of MEMS and MICROSYSTEMS Products.

* MEMS and micro system Products such as
  - Microsensors
  - accelerometers
  - actuators

* To Produce these Products are called Micro-machining (or) Micromanufacturing.

* Generally distinct three micromachining techniques used by current industry.

where

1) Bulk Micromanufacturing
2) Surface Micromanufacturing
3) LIGA Process (Lithographic aspects)
(LIGA)

* There are other process - related micromaching techniques that have been developed in recent years.

"LASER DRILLING"

1) Bulk Micromanufacturing :-

* Bulk Micromanufacturing is widely used in the production of microsensors and accelerometers.

* It was first used in microelectronics in the 1960s
* Further improvement for producing 3-dimensional microstructures took place in the 1970s.

* Bulk micromanufacturing involves the removal of materials from the bulk substrates, usually silicon wafers, to form 3D structures (Micro)

* Shaping of microsystem components of the size b/w 0.1 μm and 1mm made of tough materials such as silicon is beyond any existing mechanical means physical (or) chemical techniques either by,

1) DRY etching
2) WET etching

* Substrates that can be treated this way involve

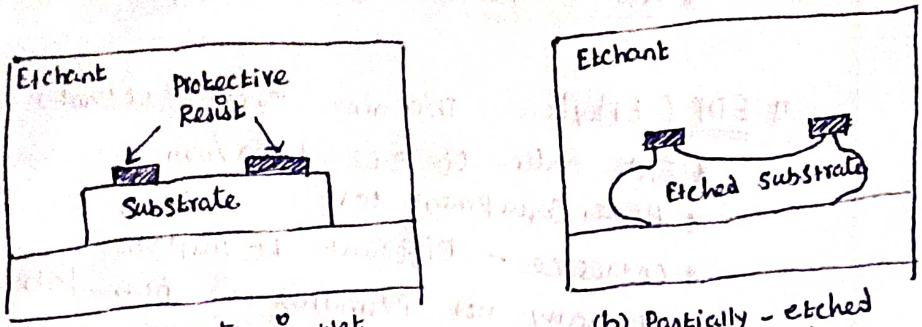
1) SiC
2) Silicon
3) GaAs
4) Quartz

* Etching, either the
  - Orientation - independent → isotropic etching
  (specific Area) - Orientation - dependent → anisotropic etching

the above technology used in bulk micromanufacturing.

OVERVIEW OF ETCHING:-

* Etching involves the exposure of a substrate covered by an etchant protection mask to chemical etchants.

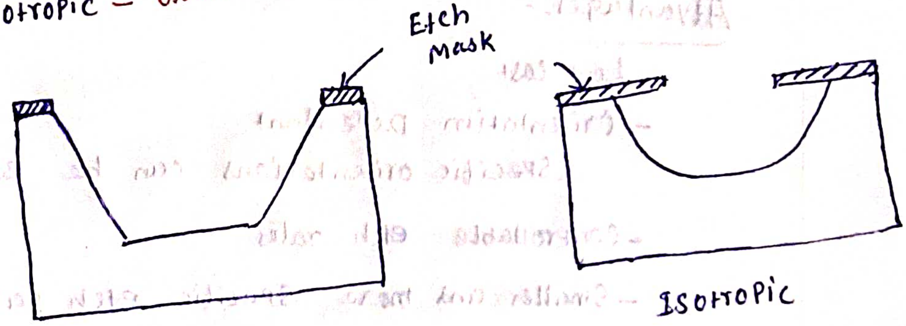


(a) Substrate in wet etching (b) Partially - etched substrate

* The part of the substrate that is not covered by the protective mask is dissolved in the etchants and removed.

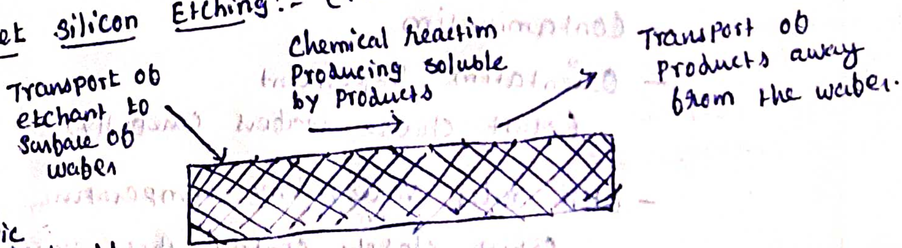
Introduction:-

* Wet Silicon Etching
* Anisotropic → orientation - dependent
* isotropic - orientation - independent



Anisotropic Isotropic

1) Wet Silicon Etching:- (Process Flow)



"For substrates made of homogeneous and isotropic materials, the chemical etchants will attack the material uniformly in all direction"

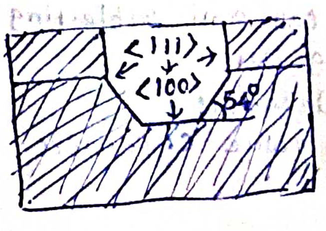
2) Anisotropic Etching:-

- Orientation Dependent
  - Miller indices become very important
  - Etch rates differ for different index planes
  - Etch rates differ for different index planes

- Etch rates differ for different index planes

* KOH etches 54.74° in respect to <100>

(Potassium Hydroxide)



- KOH (Potassium Hydroxide)
  - * Etch rates of 1-2 µm/min
  - * Low cost – widely available
    - simple equipment
  - * Corrosive – strongly Basic (PH - 12-14)
  - * Not compatible for CMOS fabrication

- EDP (Ethylene Diamine Pyrochatechol)
  - * Etch rates of 0.02 - 1 µm/min
  - * Higher equipment cost
  - * Corrosive – Different to dispose
  - * Normally not Permitted in fab-lab clean rooms
  - * Not compatible for CMOS fabrication

- TMAH (Tetra Methyl Ammonium Hydroxide)
  - * Etch rates of around 1 µm/min
  - * Comparable equipment cost with EDP
  - * Compatible with CMOS fabrication

Advantages:-

- Low cost
- Orientation Dependant
  (Specific orientations can be etched)
- Controllable etch rates
- Smaller and more specific etch patterns.

Disadvantages:-

- Contamination
- Orientation Dependent
  (Must choose wafers carefully)
- Etch rates varied by temperature and concentration
  (Must closely control these variables)
- Undercutting still an issue.

Application:-

- Radiation hardened circuits
- J-FET arrays
- Solar cell anti-reflecting surfaces
- Wave guides
- IR detectors
- High value capacitors

Isotropic Etching - Etchants (orientation Independent)

II

1) Hydrofluoric Acid (HF)
- used with silicon Dioxide
- Etch rate depends on concentration
- Extremely dangerous hard to detect

Advantages

- Inexpensive
- simple
- Highly selective

Disadvantages :-

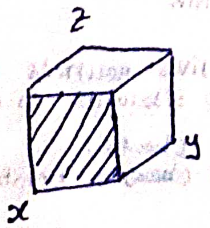
- Dangerous
- Pollution
- High likelihood of contamination
- Poor Repeatability
  * Temperature
  * concentration

Application :-

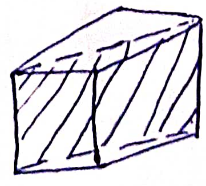
- when high etch rates needed
- Non-critical tasks
- Large geometries
- Removal of work damaged surfaces
- Rounding of sharp etched corners
- Structures and planes on single-crystal lattices.

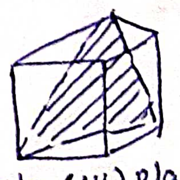
I

* Isotropic etching is hardly desirable in micromanufacturing because lack of control of the finished geometry of the work piece.
* Mostly substrate materials are not isotropic in their crystalline structures, therefore, some part of crystal are stronger and thus more resistant to etching, than others.
* Three planes of silicon crystals are of particular importance in micro machining.
  where
  110
  100
  111

(i) 

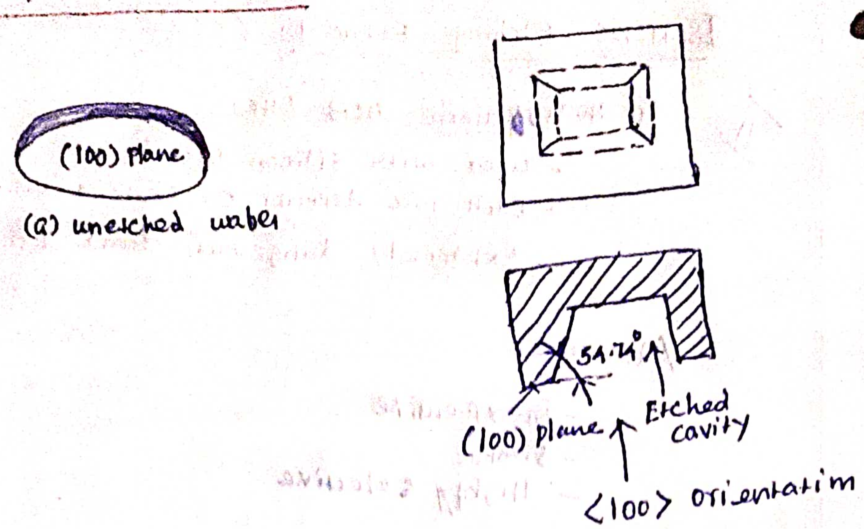
The (100) plane

(ii) 
The (110) plane

(iii) 
The (111) plane

* The most two common orientations used in the IC industry are the <100> and <111> orientations.
* <110> → wafer breaks because crystal in vertical edges.

* we will find that the (111) Plane intersects the (100) Plane at a steep angle of 54.74°



(a) unetched wafer

(b) wafer etched

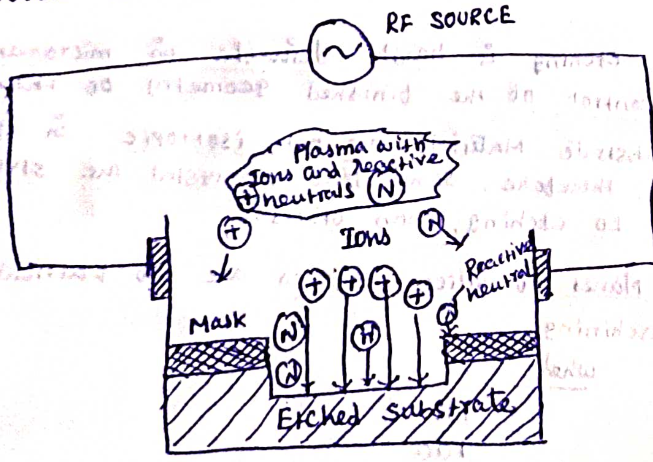
II DRY ETCHING:-

* Dry etching involves the removal of substrate materials by gaseous etchants without wet chemical or rinsing.

* There are three dry etching techniques
  - (i) plasma,
  - (ii) ion milling,
  - (iii) Reactive ion etch (RIE)

* we will focus our attention on plasma etching and a relatively new technique also called deep reactive ion etching (DRIE) in this section.

(i) Plasma Etching:-



* Plasma is a neutral ionized gas carrying a large number of free electrons and positively charged ions.

* A common source of energy for generating plasma is a radio-frequency (RF) source.

* The process involves adding a chemical reactive gas to the plasma, one that contains ions and has own carrier gas.

* The reactive gas produces → Reactive neutrals when it is ionized in the plasma

↓

The Reactive neutrals bombard the target on both the sidewalls as well as the normal surface

↓

The ions ~~changes~~ charged bombard with substrate.

↓

Etching of the substrate materials is accomplished by the high-energy ions in the Plasma

↓

High Energy reaction causes local evaporation, and thus results in the removal of the substrate Material.

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ADDITIONAL BOOK

SIGNATURE OF HALL INVIGILATOR

* Conventional dry etching is a very slow Process, at a rate of about 0.1 μm/min (or) 100 A/min

* plasma etching can increase the etching rate in order of 2000 A/min

* Plasma etching is normally Performed in high vacuum

* plasma gas etchants for selected Materials

(i) Silicon and silicon dioxide, SiO_2

(ii) silicon nitride, Si_3N_4

(iii) Poly silicon

(iv) Gallium arsenide, GaAs

ADVANTAGES

* Dry etching of silicon substrates, such as by plasma, typically is faster and cleaner than wet etching.

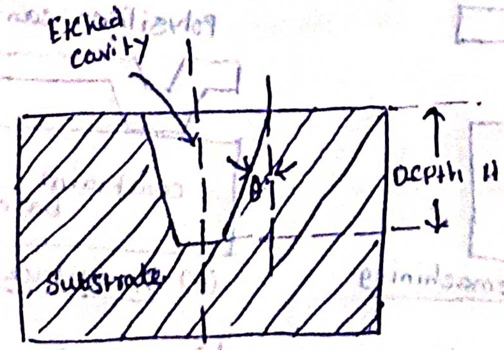
* Dry etching rate is 5 μm/min

II Deep Reactive Ion Etching :- (DRIE)

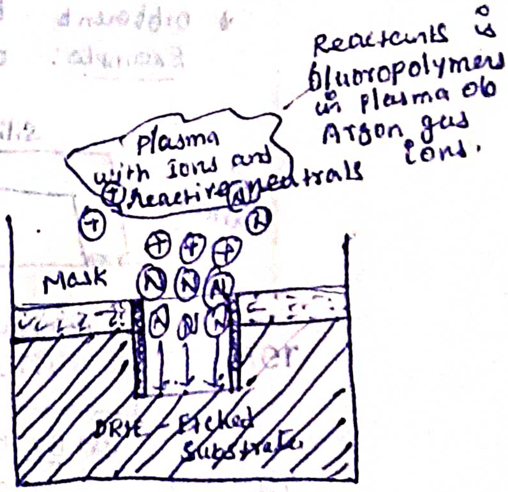
* Increase in the etching rate and the depth of the etched cavity that can be achieved with the use of plasma.

* The cavity angle θ is critical in many MEMS structures

* consequently the bulk manufacturing technique has been generally regarded as suitable only for MEMS with low aspect ratios, and many cases, with tapered cavity walls.



(a) A sidewall angle in an etched cavity.



(b) The DRIE Process

* etching in the range of 2 to 3 μm/min

* DRIE is a Process that can overcome the Problem described above.

* DRIE → bulk Manufacturing technique → MEMS Product.
↓
high aspect ratio with Virtually vertical walls $\theta = 0$

* DRIE → Protective films of a few micrometers → sidewall etching processes.
↓
high density plasma sources.

* Deposition of etching protective materials on the sidewalls. Suitable etching protective materials
    * Polymer.
    * Photoresists
    * Silicon dioxide

II SURFACE MICROMACHINING:-

* Bulk Micromanufacturing in which substrate material is removed by Physical (or) chemical means, the surface micromaching technique builds microstructure by adding materials layer by layer on top of the substrate.

* Deposition technique is in particular the Low Pressure chemical Vapor deposition (LPCVD) technique.

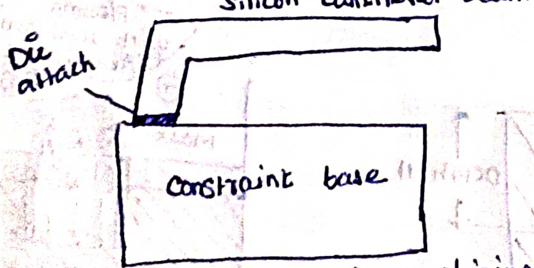
* Polysilicon is a common material for the layer materials.

* sacrificial layer usually made of SiO_2 are used to constructing the MEMS components and later removed to create necessary. (Dry/wet etching)

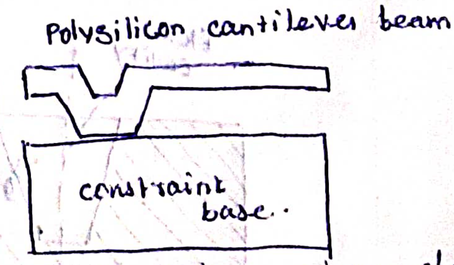
* Layer that are being added in surface micromachining are typically 2 to 5 μm thick each.

* In special applications, this range can be extended to 5-20μm

* Different b/w bulk micromaching & surface micromaching
Example:- cantilever beam



(a) BY bulk micromachining



(b) By surface micromachining

* From the diagram bulk micromaching wastage of materials

* But Surface micromachining not only saves materials, but also eliminates the need for a die attach, as the polysilicon beam can be buit on the top of the constraint base directly

Process in general

Surface - micromachined devices are typically made up of three types of components

(i) A sacrificial component (also called a spacer layer)
(ii) A microstructural component
(iii) Insulator component

* All the component deposited in thin films (Polysilicon is a popular material

* film thickness can be as long as 1 to 2000Nm and 0.1 to 5 μm thick.

LIGA PROCESS

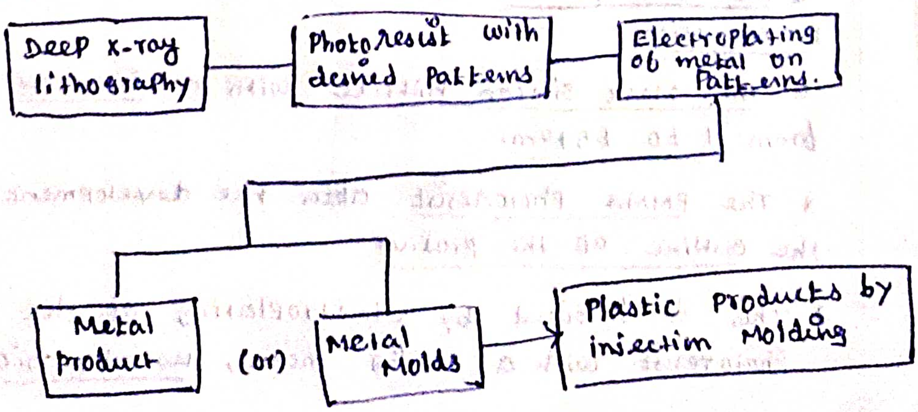
Both micromanufacturing technique
(Bulk & surface micro machining)
↓
which involve micro fabrication Process
↓
For the production of microelectronics and integrated circuit can be adaped and micro system manufacturing with for MEMS little modification, these inherited advantages are overshadowed by two major drawbacks

① Low Geometric aspect ratio
② The use of silicon - based materials (silicon → wafer based substrate + etching + thin- film deposition takes place to form the desired three dimensional geometry) → limitation → depth dimension is thus unavoidable

* LIGA process for manufacturing MEMS and microsystem is radically different from these two manufacturing technique.

* This process offers a great potential for manufacturing non-silicon -based microstructure

* LIGA indeed represent the three major steps in the process



* Deep X-ray lithography that sets the desired patterns on a thick film of photoresist.

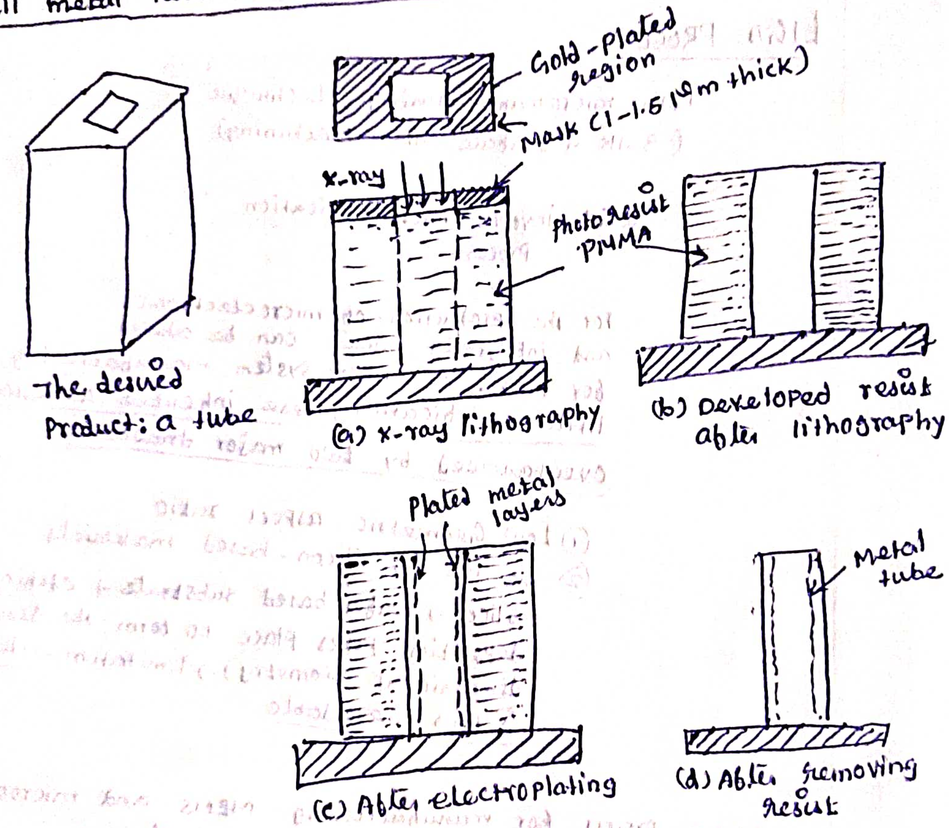
* X-rays are used as the light source in photolithography because of their short wavelength, which provides higher penetration power into the photoresist materials.

* High penetration power is necessary for high resolution in lithography and for high aspect ration in the depth.

* Short wavelength of x-ray allows a line width of 0.2µm and an aspect ratio of more than 100:1 to be achieved.

* LIGA Process Example:-

* The desired product in this example is a microthin wall metal tube of square cross-section.



* Process by depositing a thick film of photoresist material on the surface.

* The popular photoresist material polymethylmeth-acrylate (PMMA). Masks are used in the x-ray lithography.

* Thin film of gold to the area that will block x-ray transmission.

* Thin mask silicon nitride with a thickness varying from 1 to 1.5µm.

* The PMMA photoresist after the development will have the outline of the product.

* This is followed by electroplating of the PMMA photoresist with a desired metal, usually nickel

* The desired ~~tco~~ tubular product is produced after the removal of the photoresist materials by oxygen plasma (or) chemical solvents.

UNIT-II

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NAME :

SUBJECT :

ROLL NO :

BATCH :

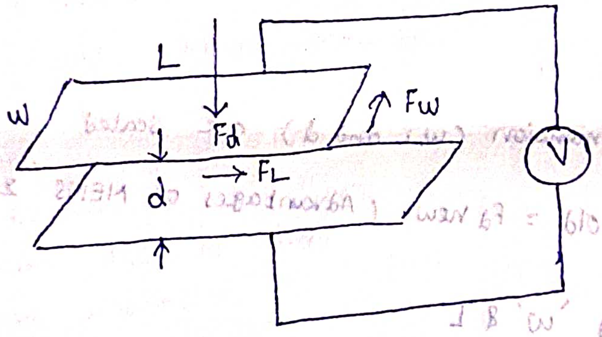
SCALING:-

-Reducing the size by a common factor

TYPES

- Dependent on the size of physical object, such as the scaling of geometry
  - Ex
    1) Electro static
    2) Electro magnetic force.
- Scaling phenomenological behavior of of microsystem
  - Ex
    1) Thermo fluids in microsystem

Effect of Scaling on Electro Static force,



The configuration of a Parallel plate capacitor (C) is represented as

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

where

$A = L * W$

Now,

$$C = \frac{\varepsilon_0 \varepsilon_r L W}{d}$$

Electric Potential Energy induced in the Parallel plate is

$$U = -\frac{1}{2} C V^2$$

Sub 'C' value

$$U = -\frac{1}{2} \frac{\varepsilon_0 \varepsilon_r L W}{d} V^2$$

$F_d = \frac{dU}{dd}$

$F_d = \frac{d\left(-\frac{1}{2}\right)\frac{\varepsilon_0 \varepsilon_r W L}{d} V^2}{dd}$

$F_d = \left(-\frac{1}{2}\right) \cdot \frac{\varepsilon_0 \varepsilon_r W L}{d^2} \cdot V^2$

Let us assume:- (Before scaling)

$W = W_{old}$

$L = L_{old}$

$\varepsilon_0\ \varepsilon_r, V \rightarrow$ constant

$d = d_{old}$

$F_{d\,old} = -\frac{1}{2} \frac{\varepsilon_0 \varepsilon_r W_{old} L_{old}}{d^2_{old}} \cdot V^2$

After scaling

$W_{new} = S \cdot W_{old}$

$L_{new} = S \cdot L_{old}$

$\varepsilon_0, \varepsilon_r, V \rightarrow$ constant

$d_{new} = S \cdot d_{old}$

$F_{d\,New} = -\frac{1}{2} \frac{\varepsilon_0 \varepsilon_r S W_{old} \cdot S L_{old}}{S^2 \cdot d^2_{old}} \cdot V^2$

$F_{d\,new} = -\frac{1}{2} \frac{\varepsilon_0 \varepsilon_r W_{old} L_{old}}{d^2_{old}} \cdot V^2$

Case:-1

1) when all dimension (W, L and d) are scaled

$F_{d\,old} = F_{d\,new}$ (Advantages of MEMS engineer)

2) only scaled 'W' & 'L'

$W = W_{old}$

$L = L_{old}$

$F_{d\,old} = -\frac{1}{2} \frac{\varepsilon_0 \varepsilon_r W_{old} L_{old}}{d^2} \cdot V^2$

$W_{new} = S \cdot W_{old}$

$L_{new} = S \cdot L_{old}$

$F_{d\,new} = -\frac{1}{2} \frac{\varepsilon_0 \varepsilon_r S W_{old} S L_{old}}{d^2} \cdot V^2$

$= -\frac{1}{2} \frac{S^2 \varepsilon_0 \varepsilon_r W_{old} L_{old}}{d^2} \cdot V^2$

$$\boxed{F_{d\,old} = S^2 F_{d\,new}}$$

$S = \frac{1}{10}$ Force is scaled down by $\frac{1}{100}$ (Advantages)

$\frac{1}{10}$ 0.01

(iii) when w, L and V are scaled down

F_d new = S^4 F_d old

↓

Disadvantages.

$$F_L = \frac{dV}{dL} \Big| d, w = \text{constant}$$

$$F_L = -\frac{1}{2} \frac{\varepsilon_0 \varepsilon_r w}{d} V^2$$

$$F_w = \frac{dV}{dw} \Big| d, L = \text{constant}$$

$$F_w = -\frac{1}{2} \frac{\varepsilon_0 \varepsilon_0 L}{d} V^2$$

③ Silicon:-

a) Available abundantly

* high quality
* Cheep.

b) Senging & electronic integrating

c) it is very high Young's modules.

Stonger than → steel

Lighter than → Al

d) when it is flexed.

e) It is having hysteries loss.

f) Less energy dissipation,

h) Little fatique,

i) Life time long,

j) high melting temp 1400°C

k) electrical conductivity can be incressed by adding improvity to the silicon.

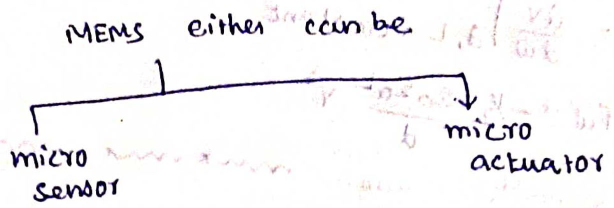
(1) MEMS :- Micro Electro mechanical system

- To introduced USA govenment

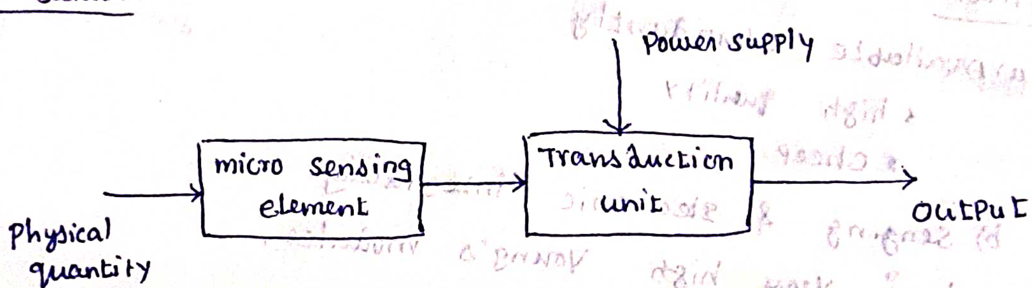
Defination :-

- Practice of making and combining miniaturized mechanical and electrical component.

- MEMS component size :- 1Nm to 1000Nm
  " device " → 20Nm to 1mm



micro sensor :-



→ Input signal → Physical quantity, chemical, biological quantity and Optical quantity.

Ex:- Temp, Pressure, light, sound, force,

→ Input signal only consider for mechanical quantity and gives electrical quantity. (Change in Resistance)

Mechanical Energy converted to Electrical Energy.

Electrical → IN / OUT
↓ ↑
Mechanical → OUT / IN

→ Different type of sensor :-

1) bio sensor,
2) Chemical sensor.
3) Pressure sensor
4) Optical sensor
5) Thermal sensor,

②

UNIT-I

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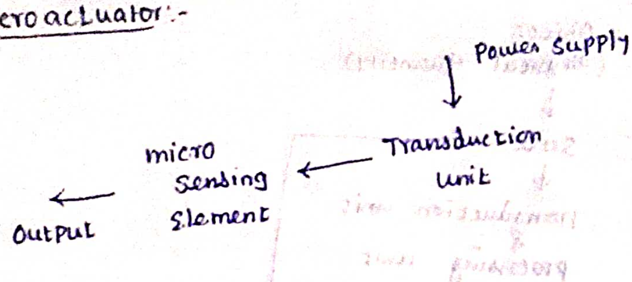
NAME :

ROLL NO :

SUBJECT :

BATCH :

Microactuator:-

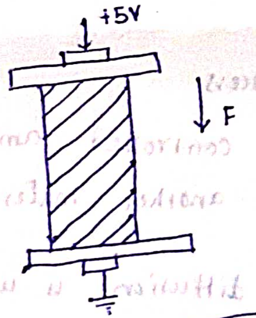


Transduction unit:-

→ It converts Input Power Supply into the form such as voltage of a transducer, which function as the actuating element (change in capacitance)

→ The application of I/P voltage to the plate ((ie) the electrode in a capacitor) can result in electrostatic force,

Example micro gripper.

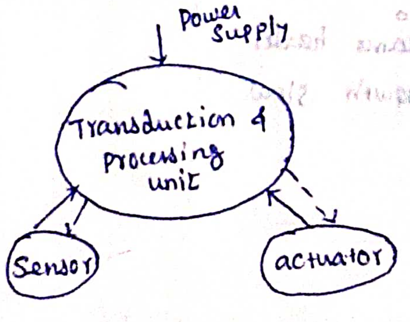


Electrical Energy converted into Mechanical energy.

Micro system:-

- It contains MEMS components that are designed to perform specific engineering function,

- unit → MESO Scaling (micro to macro)

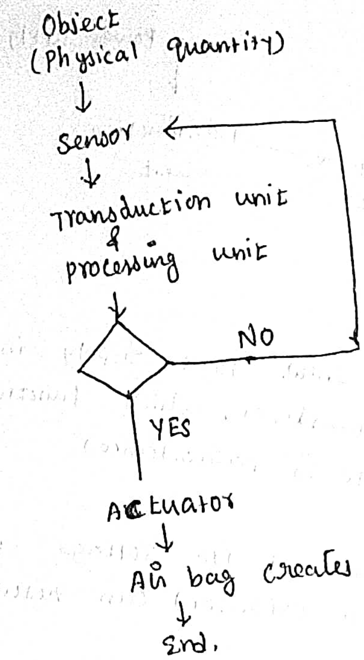


micro system

The signals received by a sensor in a micro system are converted into forms compatible with actuator through the signal transduction and processing unit.

Example

Air bag deployment



Oxidation:-

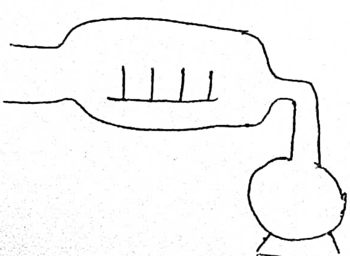
- It's a diffusion process

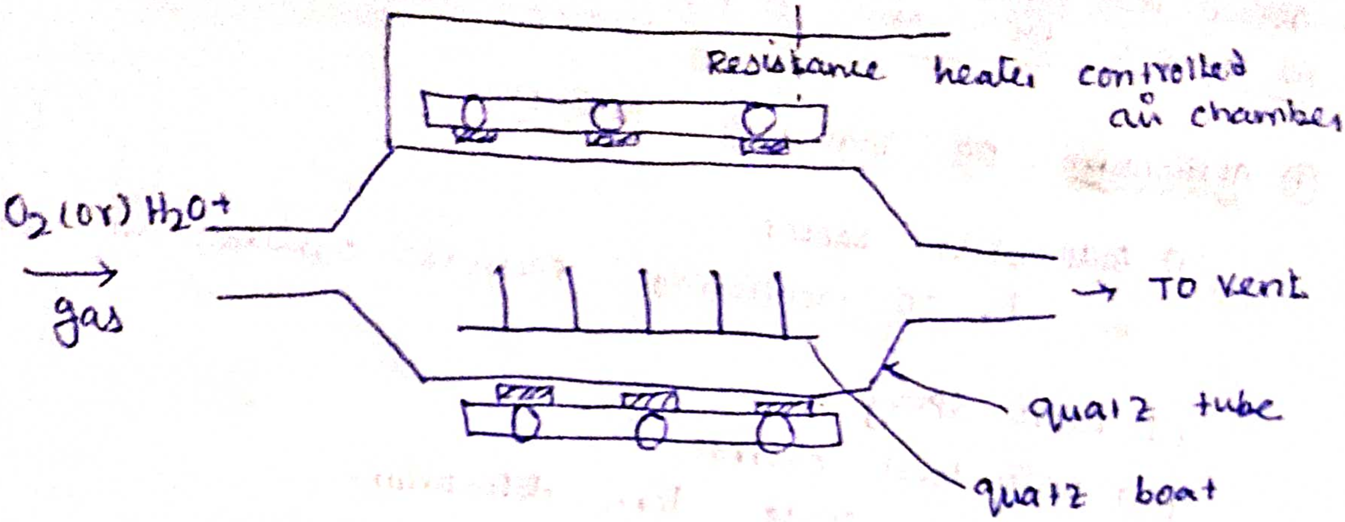
Introduction of a controlled amount foreign material into selected regions of another material

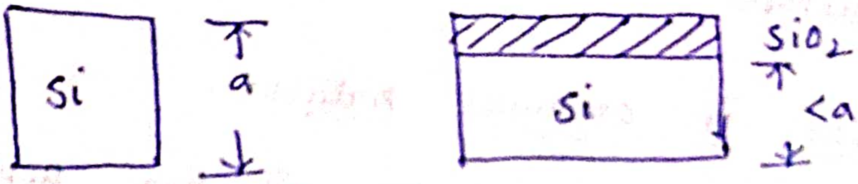
- In micro fabrication diffusion is used to oxidize a wafer surface

- " Thin film SiO_2 layer is grown"

SiO_2 growth
- Dry oxidation
  - resistance heater
  - growth slow
- Wet oxidation
  - water heat → 100°c → stream
  - Super heating state
  - $Si + 2H_2O \rightarrow SiO_2 + H_2$







$$Si_{(solid)} + O_{2\,(gas)} \xrightarrow{1000^\circ c} SiO_{2\,(solid)}$$

$$Si\,(solid) + 2H_2O\,(steam) \rightarrow SiO_2\,(solid) + 2H_2\,(gas)$$

MEMS MARKET:-

- As a new MEMS and microsystem Products have become available the market for these Products has been expanding rapidly.

① Application of Industrial Products:-

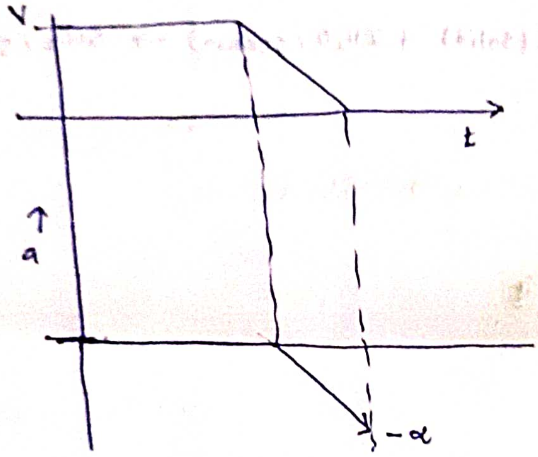
(i) Automobile sector.
↳ To monitoring pressure system in 2007, USA

(ii) Paint spray.
(iii) water level control
(iv) Telephone cable leak detection.

② Application in consumer Products:-

(i) MEMS accelerometer for air bag Deployment.
(ii) a sensor → to measure accelaration.

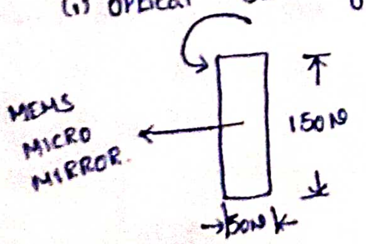
Ex



(ii) Bicycle computer
(iii) Digital tire pressure gages.

③ Application in telecommunication:-

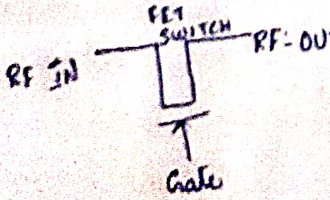
(i) Optical switching and fiber-optic coupling.



Advantages:-

Better communication.

(ii) RF MEMS SWITCH:-



Switch closed
1V — 0.96V → R↓

Open R=α
1V —o o— 0V → R↑

(iii) Tunable resonators.

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WITH COURAGE AND FAITH

(4) Health care:-

micro pump's | micro needles ↓ micro pump's ↓ for insulin injection.

UNIT-2

Micro manufacturing

Engg fun.
* Electro mechanical
* Electro chemical

components 1N to 1mm

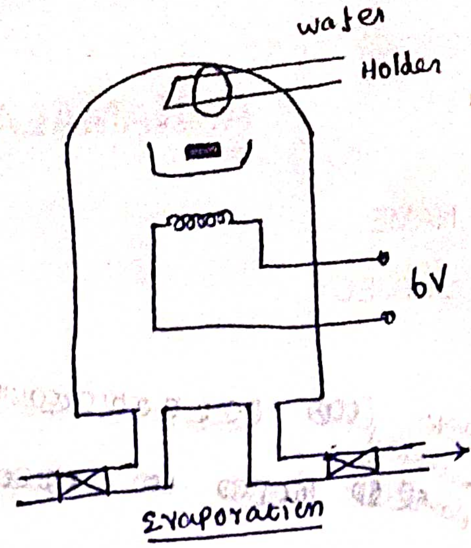
device 20N to 1000N (1mm)

MEMS
- Basic process
  - Deposition
    - PVD (Physical)
      - Sputtering
      - Evapo-ration
    - CVD (Chemical)
      - LPCVD (Low Pressure)
      - PECVD (Plasma enhanced)
      - Thermal Oxidation
  - Patterning (Design) overall
    - Lithography
      1) Photo Lithography
      2) Electron beam Lithography
      3) Ion-beam Lithography
      4) X-ray Lithography
    - Diamond Patterning
  - Etching
    - WET ETCHING
      1) Isotrophic etching
      2) Anisotrophic etching
      3) Hydro fluoric acid etching
      4) Electro chemical etching
    - DRY ETCHING
      (1) Vapour etching
        - Xenon difluoride etching.
      (2) Plasma etching
        (1) Sputtering
        (2) Reactive Ion etching.

PVD (Additive Process)

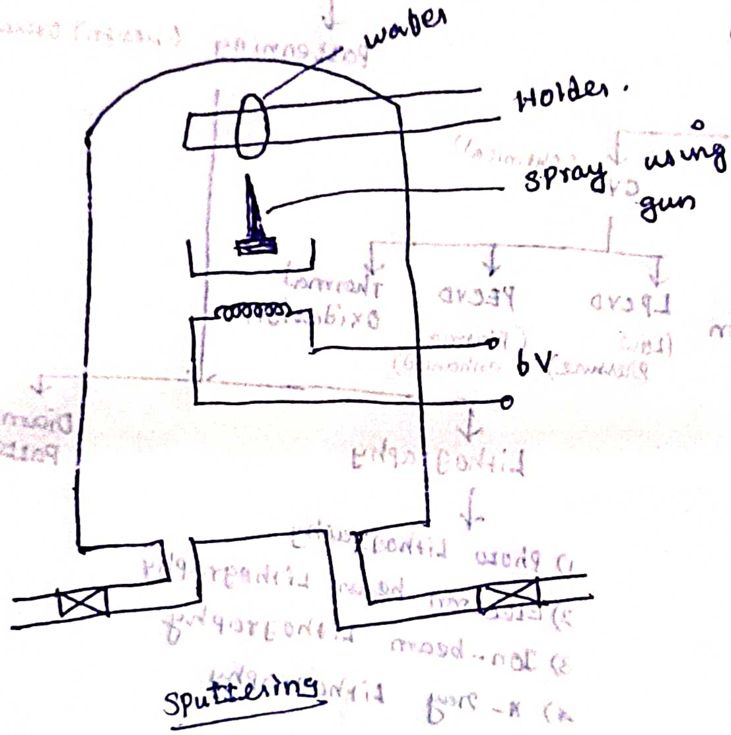
1) Sputtering / Evaporation

→ Evacuate
→ apply voltage and heat 400°C
→ 'Al' melts and evaporate and deposited.



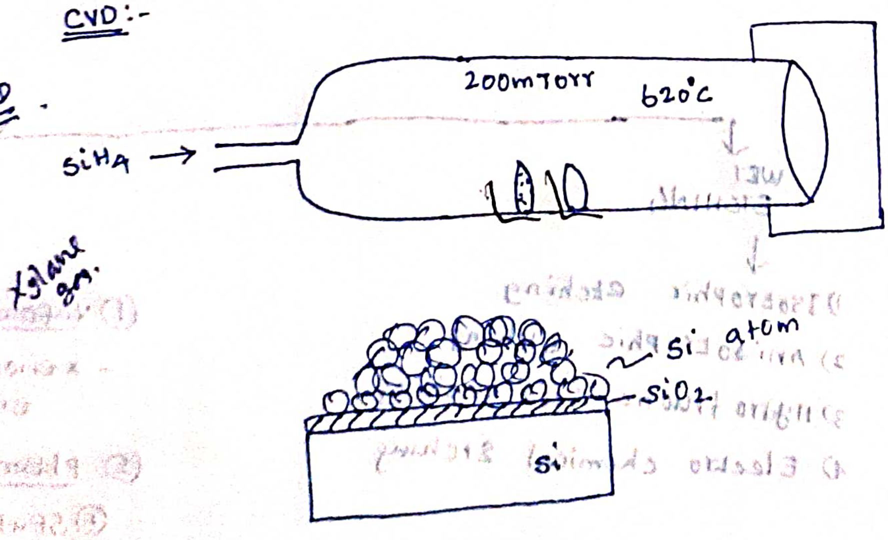
→ Poor step deposition (coverage)

→ sputtering → spray by using gun to spread uniformly in wafer.



CVD:-

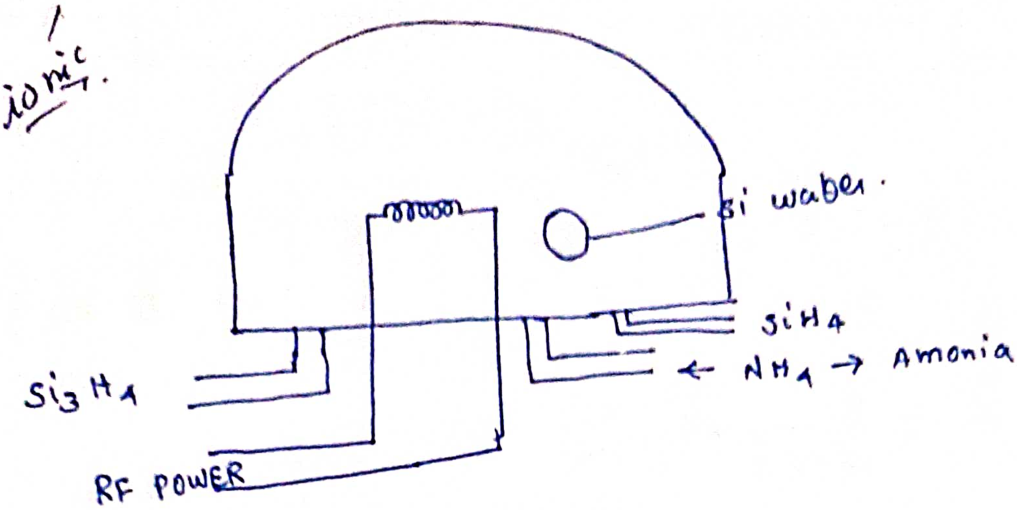
LPCVD.



$SiH_4 \xrightarrow[200-250\ min]{620°C} Si + 2H_2$

PECVD (Plasma Enhanced chemical vapour Deposition)

ionic.



Etching:-

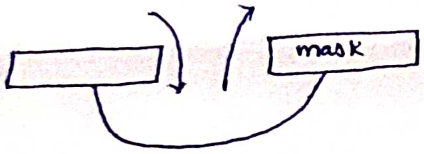
Process of selectively removing the material (Removing the atoms),

Etching
- ↓ wet etching
  - ↓ liquid /solution are used for etching
- ↓ Dry etching
  - ↓ - Most suitable for HAR structures.
  - - very costly
  - - Poor yield
  - - Batch Processing is not Possible.

wet etching
- ↓ isotrophic etching
- ↓ Anisotrophic etching
  - KOH
  - → TMAH((CH$_3$)$_4$NOH)
  - EDP(Ethylene Diamine Pyrochatech)

Isotrophic etching

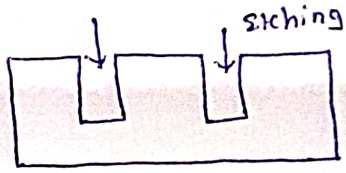
1) Etching very fast
2) By chemical action.
3) Direction independent
4) Same level in each direction



5) Edge rate are same.
6) Chemical used → HNA
   - HF acid (HF)
   - Nitric acid (HNO_3)
   - Acetic acid (CH_3COOH)

Anisotrophic etching

1) Etching slow
2) By reactive ions.
3) Direction dependent
4) $x \neq y \neq z$



5) Etch mask selectivity
6) Application (micro electronic (MEMS))
7) Edge rate different.

__micromachining__ To achieved by combining lithography with substrate.

Micromachining
- ↓ Bulk micro machining
- ↓ Surface micro maching
- ↓ LIGA process

Bulk micro machining

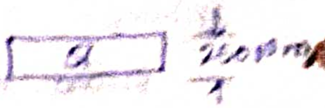
1) Basically a substractive process
2) Generally dealing with thick film's
3) Lithography & etching

Surface micro maching

1) Basically it is additive process
2) generally deals with thin film.
3) Deposition, litho & etching.

LIGA process

used for H·A·R structure.

Step	Description	Structure.
Starting material Si wafer		
1) Cleaning	RCA cleaning with HF dip	
2) oxide growth	Dry oxidation	
3) cleaning	RCA	
4) Lithography	UV-lithography	
5) strip	Remove Photo resistance	
6) Cleaning	RCA	
7) Poly deposition	PCVD 620°C, 150m torr	
8) Lithography		

ANNAMALAI UNIVERSITY

NAME :

SUBJECT :

ROLL NO :

BATCH :

Oxidation:-

- It is diffusion process

- Defination:-

  The thin film of SiO_2 layer is grown of silicon substate

- There are three principles uses of SiO_2 in micro system

  1) Thermal & Electrical insulator
  2) mask in edging of silicon substrate
  3) sacritical layer in surface maching

TYPES

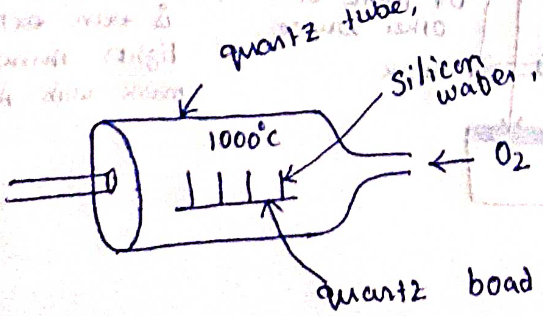
- Dry oxidation
- wet oxidation

Dry oxidation

1) SiO_2 can be produced by heating silicon in an oxitand such as oxgen with out streem,

$$Si + O_2 \xrightarrow{1000^\circ C} SiO_2$$

2) growing will be slow

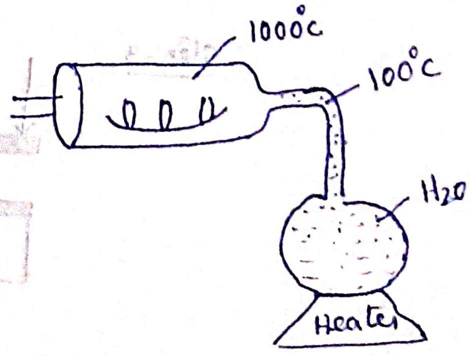


wet oxidation

1) SiO_2 can be produced by heating silicon in an oxitand such as oxsen with steam.

$$Si + 2H_2O \xrightarrow{1000^\circ C} SiO_2 + 2H_2$$

2) growing will be fast

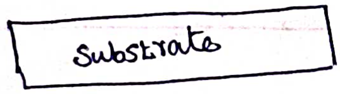


PHOTOLITHOGRAPHY :-

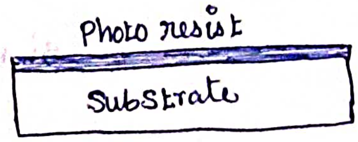
- microsystems almost always involve complex three dimensional structural geometry in microscale.
- It is providing photolithography (or) microlithography appears to be the only viable way for producing high precision patterning.
- Photolithography is one of the most important steps in micro fabrication
- microelectronics patterns
  Ex
  1) P-N junction.
  2) diodes
  3) capacitors
  4) integrating circuit.
- Microsystem patterns.
  Ex
  bulk micro manufacturing
  Surface " "
- General procedure of photolithography :-

Step:-1

1) This substrate can be a silicon wafer.

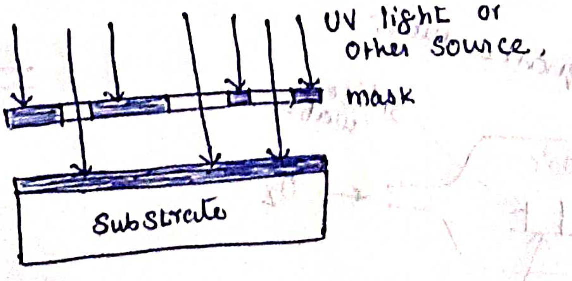


Step:-2



* A photoresist is first coated onto the flat surface of the substrate
* commercially available photoresists of both positive resist, negative resist.

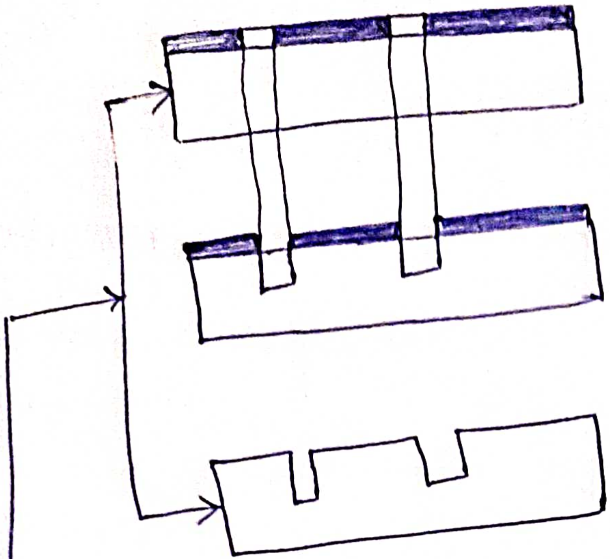
Step:-3



* The substrate with photoresist is then exposed to a set of lights through a transparent mask with the desired patterns.

* **Processes:-**
  (a) Development
  (b) Etching
  (c) Resist removal

Positive resist



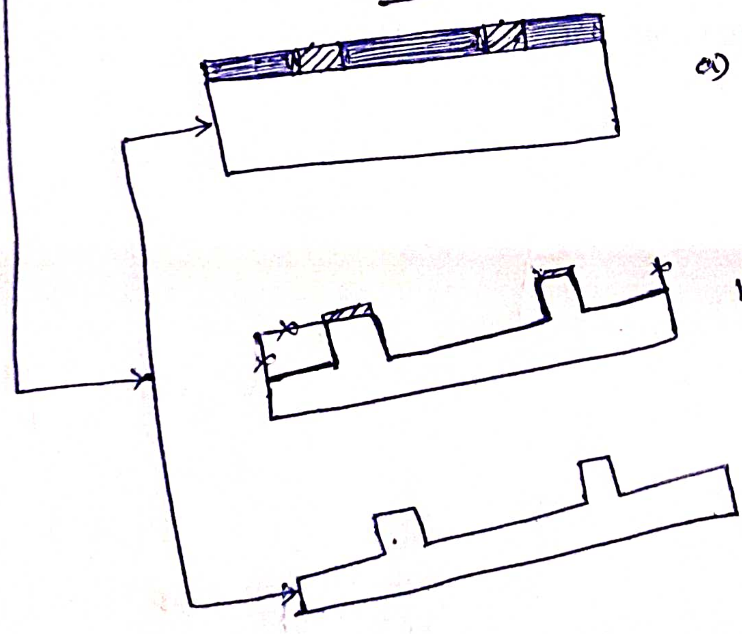
(a) Development

(b) Etching

(c) Resist removal

* **Positive resist**
  1) PMMA
  2) Two-component DQN resist involving diazo-quinonester.
  3) wavelength 220nm
  4) KOH / TMAH

Negative resist



a) Development

b) Etching

c) Resist removal

Negative

1) Two component bis (aryl) azide rubber resists
2) kodak KTFR.

K. DEVARAJAN
LECT/ECE

BMM: BULK MICRO MANUFACTURING (OR) MICROMACHINING.

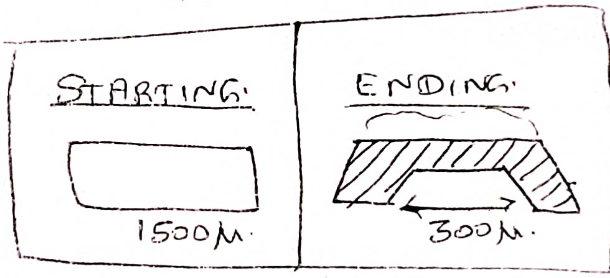
- it involves the removal of materials from the bulk substrates, usually Silicon wafers, to form the desired 3D geometry of the microstructures.
- it is a subtractive process dealing with THICK MICRONS - usually 5 μ.

FOUR IMPORTANT STEPS OF BMM:

1) THICK FILM FORMATION.
2) LITHOGRAPHY
3) ETCHING

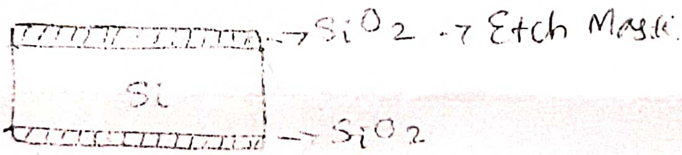
[4 DOPING].

PRESSURE SENSOR:



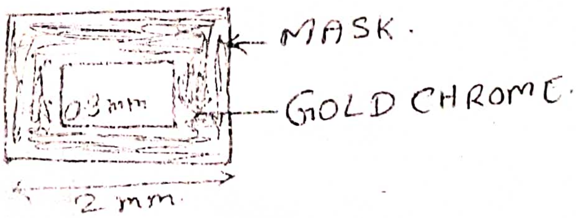
① THICK FILM FORMATION

OXIDATION

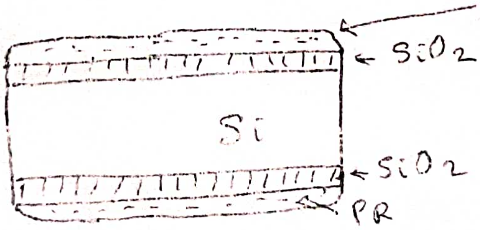


② LITHOGRAPHY:

1)

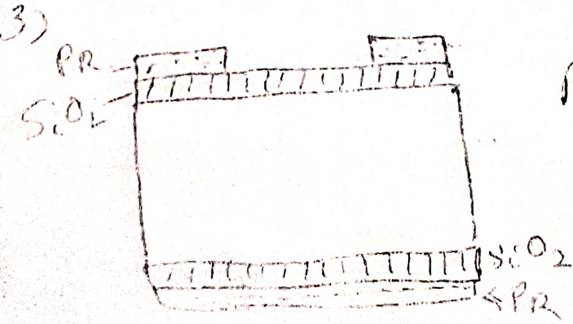


2)



Photoresist [PR]
- Semisolid material
> By Spinning it is uniformly spread.

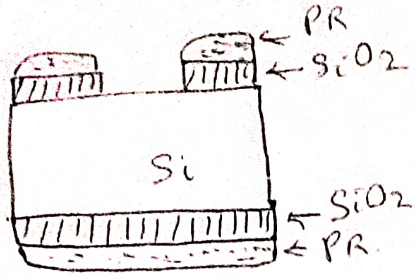
3)



After Litho (UV exposure) and Developer solution.

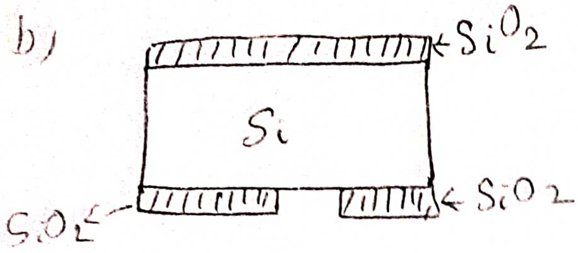
3) ETCHING:

a)



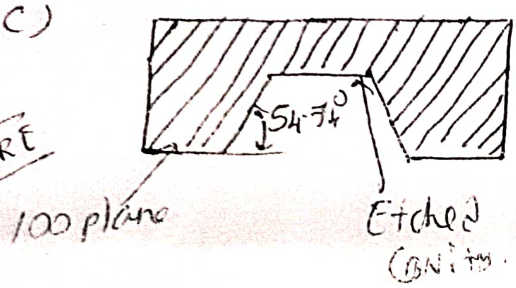
→ Oxide (i.e. SiO_2) etching by Hydro Fluoric Acid.

b)



→ ~~After~~ Use Acetone to remove Photo Resist.

c)



FINAL STRUCTURE

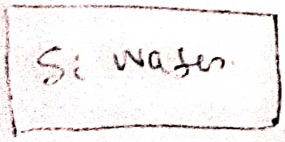
→ ANISOTROPHIC ETCHING OF SILICON SUBSTRATE THEN REMOVE SiO_2 by. HF acid.

SURFACE MICROMACHINING:

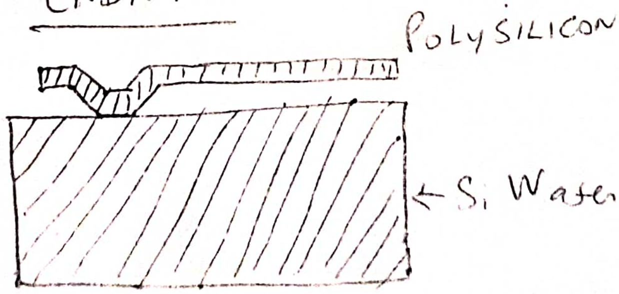
.. it involves the technique to build micro structure by adding materials layer by layer on the top of the substrate.

- it is an additive process.
- Generally deals with thin film deposition, Lithography and etching.

STARTING:



ENDING:



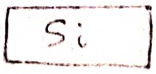
POLYSILICON CANTILEVER BEAM

EITHER USED AS MICROACCELEROMETER (OR) MICRO ACTUATOR

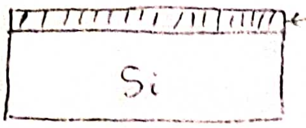
3 Components:

1) a Sacrificial Component (Spacer layer) - PSG - Phosphosilicate glass.
2) Micro Structural Component [POLY SILICON]
3) an insulator Component.

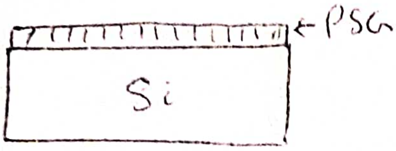
PROCESS FLOW:

① 

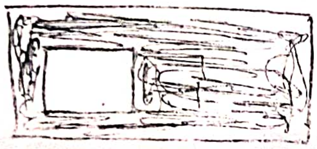
→ Cleaning → RCA Cleaning with HF dip. (Remove any contamination and oxide layer)

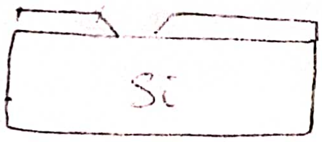
② 

Sacrificial layer → either PSG (or) SiO_2 deposited by LPCVD techiane to act as Sacrificial layer.

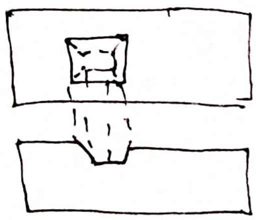
③ 

→ Cleaning

④ 
→ Mask 1 for etching [To cover the Surface of PSG for Subsecaunent etching]

⑤ 

→ After Lithography.

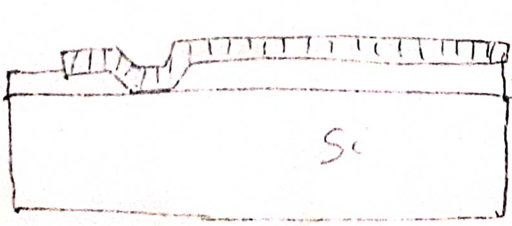


⑥ Remove Photo resist by acetone

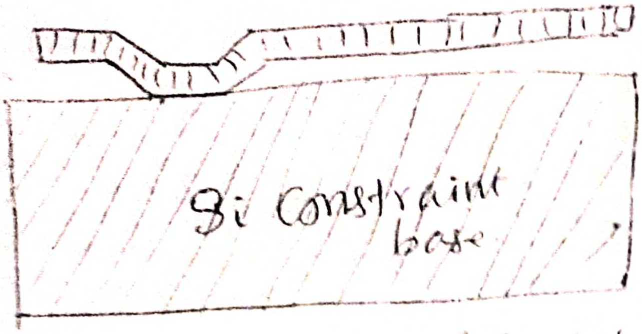
⑦ cleaning → RCA

⑧ 
← Mask 2 for deposition of PolySilicon.

⑧a 

⑨ 

Cleaning



+ Polysilicon [PSG can be etched by HF 1:1 ratio]

After etching of Sacrificial layer

POLYSILICON CANTILEVER BEAM

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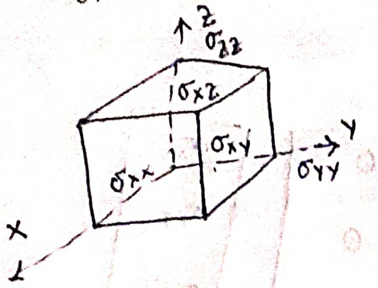
LECT/ECE

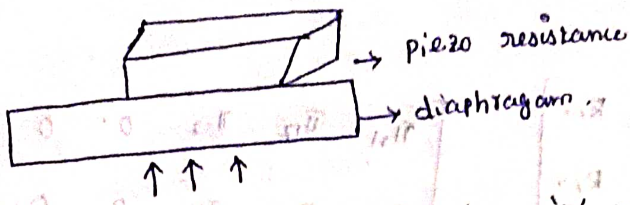
UNIT-5

ANNAMALAI UNIVERSITY

PIEZO RESISTIVE PRESSURE SENSOR:-

Piezo resistance is defined as change in electrical resistance of solids when subjected to stress.





generally the silicon crystal whether its 'P'-type (or) 'N'-type exhibities. exalent piezo resistive effect is the crystal is Anisotropic as made the relactimship b/w change of resistance & stress field more complex.

$$\Delta R = \Pi \sigma$$

where

$$\Delta R = [\Delta R_{xx}, \Delta R_{yy}, \Delta R_{zz} \; \Delta R_{xy} \; \Delta R_{yz} \; \Delta_{zx}]^T$$

Represents the change of resistance corresponding to stress components

$$\sigma = [\sigma_{xx}, \sigma_{yy}, \sigma_{zz} \; \sigma_{xy} \; \sigma_{yz} \; \sigma_{zx}]^T$$

$\sigma \rightarrow$ Normal stress compenents. + shear stress compments.

$$[\sigma_{xx} \; \sigma_{yy} \; \sigma_{zz}] + [\sigma_{xy} \; \sigma_{yz} \; \sigma_{zx}]$$

$\Pi \rightarrow$ Piezo resistive co-efficient matrix.

$$\begin{bmatrix} \Pi_{11} & \Pi_{12} & \Pi_{12} & 0 & 0 & 0 \\ \Pi_{12} & \Pi_{11} & \Pi_{12} & 0 & 0 & 0 \\ \Pi_{12} & \Pi_{12} & \Pi_{11} & 0 & 0 & 0 \\ 0 & 0 & 0 & \Pi_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & \Pi_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & \Pi_{44} \end{bmatrix}$$

where

$\Pi_{11}, \Pi_{12} \rightarrow$ are associated with normal stress compment,

$\Pi_{44} \rightarrow$ is related to the shear stress compment.

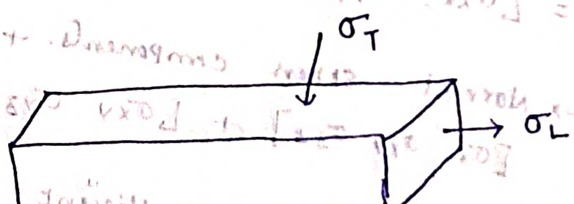
* The achive value of this is three co-efficient of depen... on the angle oo the Piezo resistor with respect to Silicon crystal latices.

$\therefore$ $[\Delta R] = [\Pi] \; [\sigma] \rightarrow$ stress matrix,

$$\begin{bmatrix} R_{xx} \\ R_{yy} \\ R_{zz} \\ R_{xy} \\ R_{yz} \\ R_{zx} \end{bmatrix} = \begin{bmatrix} \Pi_{11} & \Pi_{12} & \Pi_{12} & 0 & 0 & 0 \\ \Pi_{12} & \Pi_{11} & \Pi_{12} & 0 & 0 & 0 \\ \Pi_{12} & \Pi_{12} & \Pi_{11} & 0 & 0 & 0 \\ 0 & 0 & 0 & \Pi_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & \Pi_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & \Pi_{44} \end{bmatrix} \begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \sigma_{xy} \\ \sigma_{yz} \\ \sigma_{zx} \end{bmatrix}$$

$6\times1 \qquad 6\times6 \qquad 6\times1$

Generally, all application MEMS & micro system silicon Piezo resistor exist in the form thin Strip in such cases only the in-plane stress in the 'x' & 'y' direction need to the accountable.



$\sigma_L \rightarrow$ Longitudidal Stress.

$\sigma_T \rightarrow$ Transverse stress component

→ So the Change oo electric resistance in a silicon P.R can be expressed as

$$\frac{\Delta R}{R} = \Pi_L \sigma_L + \Pi_T \sigma_T$$

$\Pi_L \rightarrow$ Piezo resistance co-efficient along the longitudidal direction that is 'x'- direction.

$\Pi_T \rightarrow$ Piezo resistance co-efficient along the tangent. in 'y' direction

$\sigma_L, \rightarrow$ Stress component oo longitudidal direction

$\sigma_T, \rightarrow$ Stress component oo transverse direction

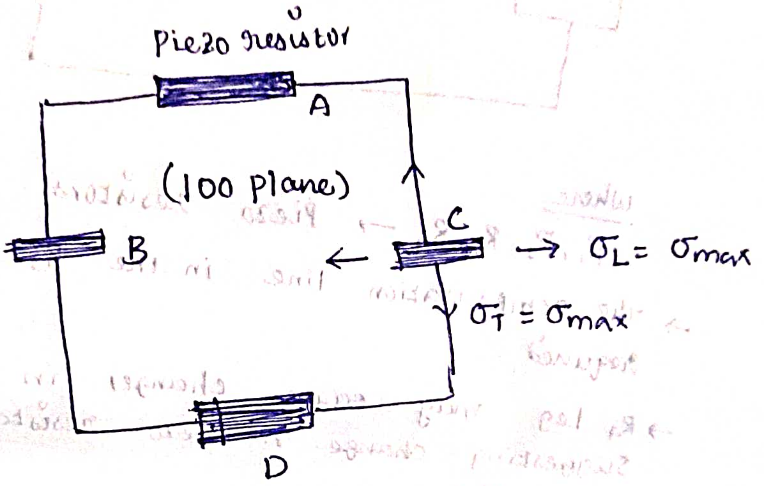
$\pi_L = \frac{1}{2}[\pi_{11} + \pi_{12} + \pi_{44}]$

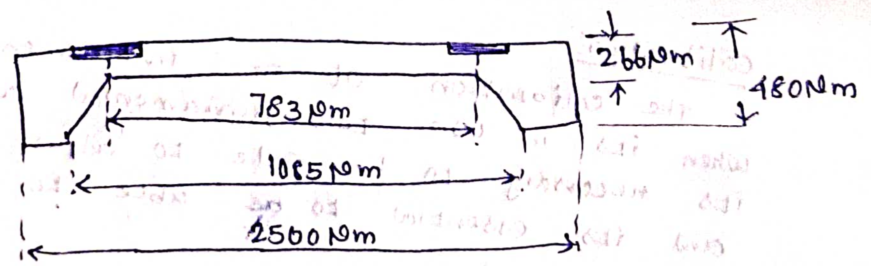
$\pi_T = \frac{1}{2}[\pi_{11} + \pi_{12} - \pi_{44}]$

$$\frac{\Delta R}{R} = \pi\sigma$$

Pressure Sensor:-

There are fome identical Piezo resistance A, B, C, D diffused in the location at the top face of the silicon die. So resistor A & D are subjected predominately trams force stress compment σ_y (or) σ_T that is normal to the horizontal edges, B & C are subjected to a longitudinal stress σ_L (or) σ_x that is normal to the vertical edges.





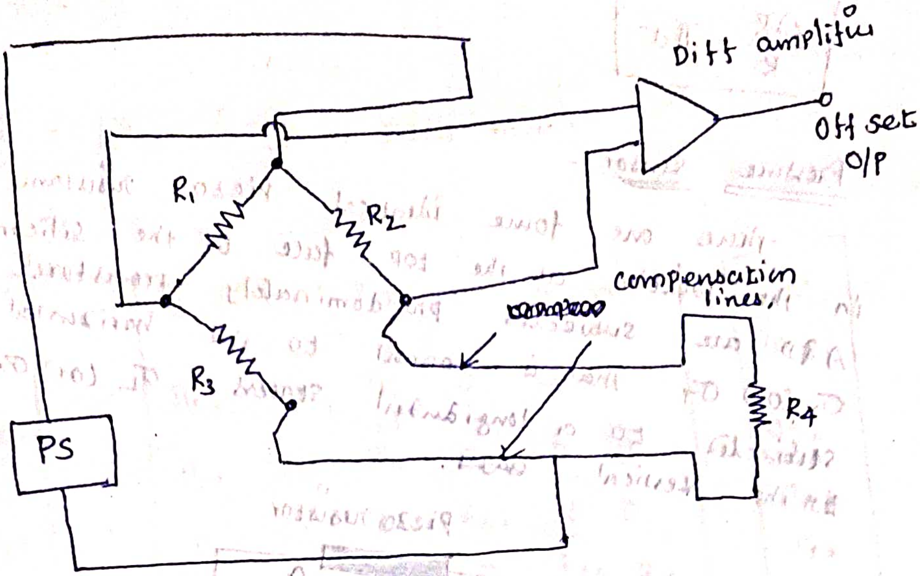
Because of squene plane gemenrric of diaphragm there is subjected to be uniform pressure loading at the top surface, the pending moments. normal to all edges are equal in magnetic thus let $\sigma_L = \sigma_T = \sigma_{max}$. suppose the diagram of the 100 plane and bothe stress are alonge the 100 direction the piezo resistive co-efficient $\pi_L = \pi_T = 0.02\pi_{44}$

Disadvantages:-

1) silicon Piezo resistor is the strong temp dependens. of they are Piezo resistivity. the sensivity of the piezo resistivity to be applied stress deteriorties rapidly with ↑ of temp.

Signal conditioning and calibration:-

→ Due to very small fractional changes of piezo resistance with stress, the piezo resistors are generally used in a bridge circuit.



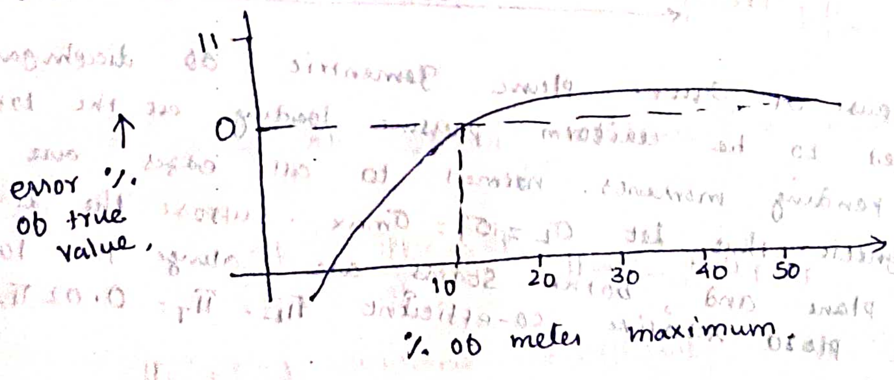
where
R_1, R_2, R_3, R_4 → Piezo resistors

→ The compensation line in the R_3 leg of the bridge is required.

→ R_4 Leg may cause changes in line resistance. these change suggesting change in piezo resistance by using the compensation line,

Calibration:-

The calibration of an instruement may be corrected when its in use two fundamental adjustment are essential its necessary to be able to adjust the instrument zero and its essential to be able to adjust the scalls span.



Graph relating error to meter reading.

* In piezo resistive pressure sensor, it's possible that after some time the sensor suffers from a permanent set (PER) causing a zero error.

ANNAMALAI UNIVERSITY

NAME :

SUBJECT : wafer bonding

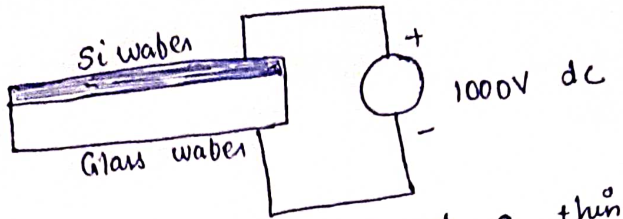
UNIT-2

ROLL NO :

BATCH :

ANODIC BONDING :-

- attaching silicon wafers to thin glass (or) quartz substrates.



- Si wafer is placed on the top of a thin glass constraint base. A high dc voltage source is applied across the set of temp b/w 450 and 900°C
- applicable for LAR of the bonded compounds.

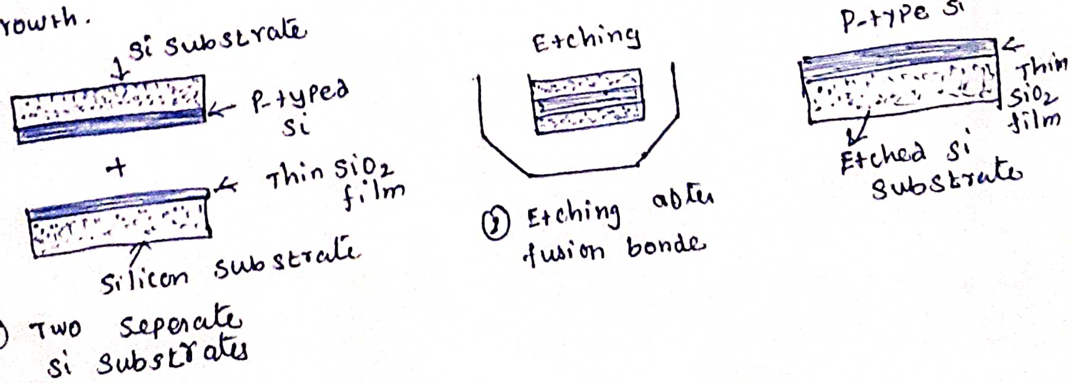
FUSION BONDING :-

- Bonding two Si wafers (or) substrates w/o the use of intermediate adhesives.

1) Clean the bonding surfaces
2) Then Polish, then hydrophillic by exposure to boiling nitric acid.
3) Two surfaces then naturally bonded even at room temp
4) strong bonding occurs at 1100°c to 1400°c application
   ↓
   Pressure sensors, accelerometers.

SOI → Silicon on Insulator :-

- It is used in microelectronics to avoid leakage of charges in P-N junctions.
- It involves bonding the Si with an amorphous crystal material such as SiO_2 by way of epitaxial growth.



① Take 2 substrates

One: Si + Boron atoms → P-silicon

Another: Si + SiO_2 → Si + SiO_2

② Join two substrates by fusion bonding

③ Bonded substrates are then exposed to etching

④ The heavily p-doped region can act as an etch stop

⑤ Finally → P-silicon layer + SiO_2 insulator.

Silicon On Insulator.