# UNIT-III

## Micro SENSORS:-

Sensor is an electronic component module or subsystem whose purpose is to detect events or changes in it's environment and send the information to other electronics.

## Thermal MicroSensors:-

Thermal Sensors are sensors that measure a primary thermal Quantity such as temperature, heat flow or thermal conductivity.

Thermal Sensors are basically known as Thermal detectors.

Thermal detection process consists of 2 stages

1.) Thermal detectors have an absorption layer that absorbs and converts light into heat and provide an electric signal output

2.) Increase in temperature of the absorbing material causes variations in the material properties.

Thermal detectors are mainly classified into:-

1.) Thermopile detectors
2.) Bolometers
3.) Pyroelectric detectors.

Thermopile detectors have a structure in which large no.of thermocouples are serially connected on a silicon substrate. and their sensitivity increases as more thermo couples are used. This means that larger the photosensitive area the higher in sensitivity increases because the no. of thermocouples is proportional to th size of the photosensitive area.

In bolometer is a resistance element with high TCR (Temperature Coefficient of Resistance) and a small heat capacity. Absorbed light radiation changes the temperature and then the resistance of a bolometer.

Photo sensitive area uses a Bolometer resistance made up of thermo electric conversion materials. Bolometer sensitivity does not depend on the size of the photosensitive area, detectors can be fabricated that have a small photosensitive area yet no drop in sensitivity.

Pyroelectric detector is a thermal detector.

Temperature fluctuations produce a charge change on the surface of pyroelectric crystals, which produces a corresponding electric signal. This temperature gradient is created by the absorption of light.

Comparison:-

| Thermopile (two step Process) | Bolometer | Pyroelectric (Single step Process) |
|---|---|---|
| Self-generating effect | Need an external bias which introduces noise | Need modulated Radiation. |
| No need of external bias | | |
| No. of thermocouples $\propto$ (Size of the Photosensitive area) | Sensitive is not dependent on Photo sensitive area | Higher responsivity and faster. |

| Photon Detector | Thermal Detector. |
|---|---|
| → Photon Detectors are sensitive and faster | → slower |
| → Single step transduction Process | → two-step transduction process. |
| → Must be Cooled for higher sensitivity | → operate well at room temperature. |
| Ex:- PIN Detector. | |

Detector characterization:-

→ Time Constant:-

$T = R_{th} H$

Product of heat resistance and heat Capacitance

$R_{th}$ = detector thermal Resistance

H = heat Capacitance.

→ Responsivity:- (R).

Ratio of the detector output and the input power

→ Noise Equivalent power:- (NEP)

Signal power that gives ratio of signal to Noise ratio ~~of~~ and the responsivity.

→ Relative detectivity:- $D^* = [\sqrt{A_D B} / NEP]$

$A_D$ = Absorbing area of detector

B = Band width

NEP = Noise equivalent Power.

# Thermopile Detectors:-

## Thermopile or Thermo Couple

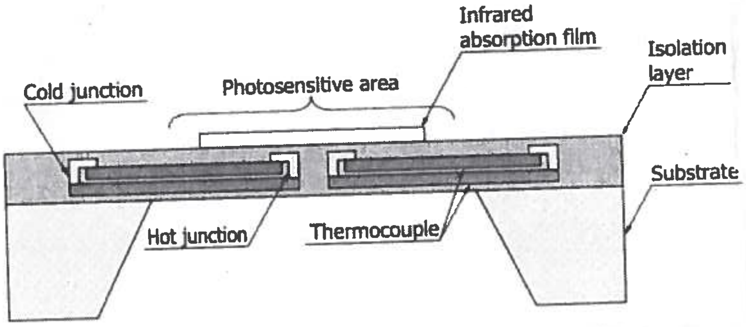
A ThermoCouple is made by simply joining two dissimilar conductors.

Several thermo Couples Conducted in series to make a thermo pile

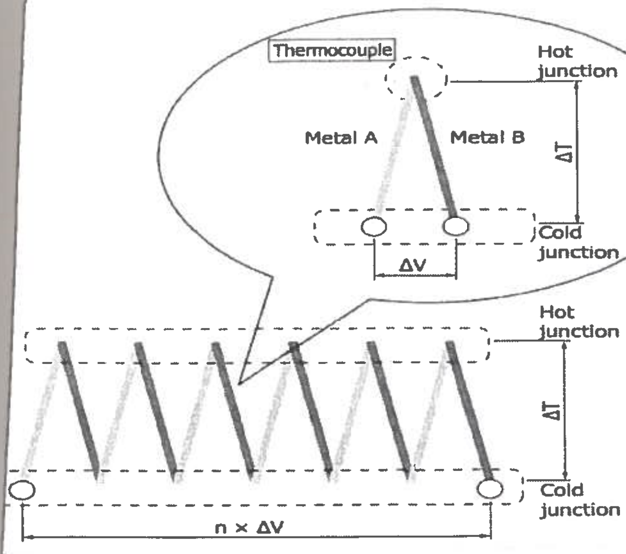
Thermopile detectors are thermal detectors that utilize Seebeck coefficient.

Thermopile detectors have many thermoCouples that are serially connected on a silicon substrate to magnify the temperature difference between the hot and Cold Junctions.

Thermopile detectors use materials that have a large seebeck coefficient and are easily formed by SemiConductor process.



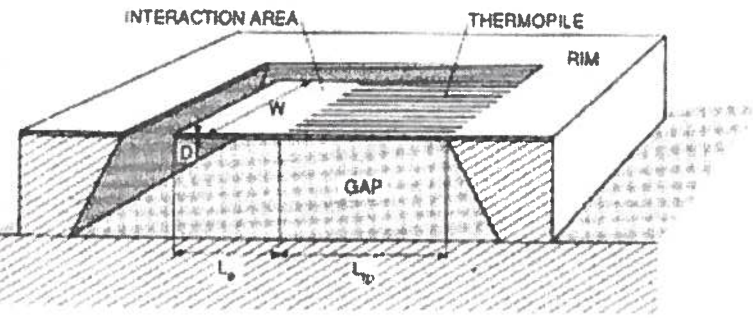
When infrared light enters a thermopile detector having the above mentioned structure, the hot Junction on the membrane heats up and Produces a temperature difference (ΔT) between the hot and cold junctions accompanied by the generation of a thermal electromotive force (ΔV).



Single/dual/Quad element types have large photosensitive areas and are manufactured by bulk processing technology with high Workability.

Etching is performed from the backside of the Substrate to form the photo sensitive area in a membrane state so that the hot and Cold junctions are thermally isolated from each other to achieve high sensitivity.

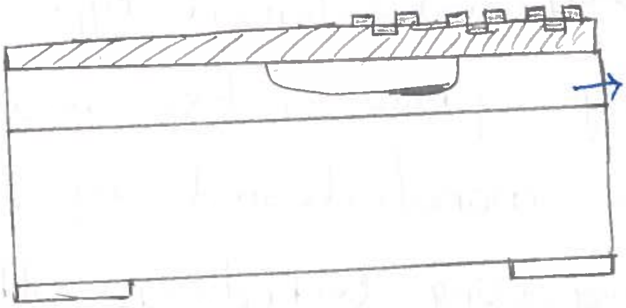
### Thermopile on Cantilever.



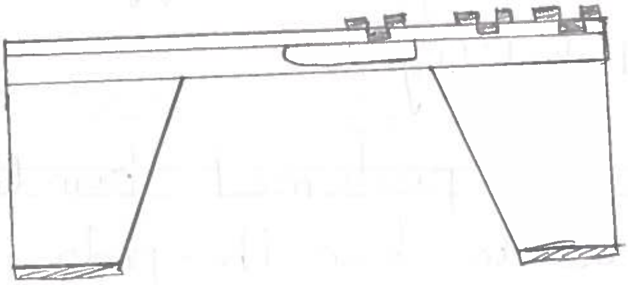
Cantilever is hanging. This structure has an advantage over previous structure i.e hot junction is nearer to the interaction area (absorber).

Here the sensitivity is much higher.

The disadvantage is that this kind of the Cantilever ∵ it is held in one edge and one side. So automatically this is much more fragile.

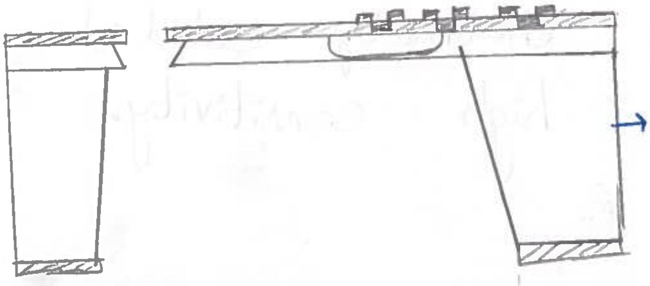


→ P type silicon wafer on top of it is an n epi layer.

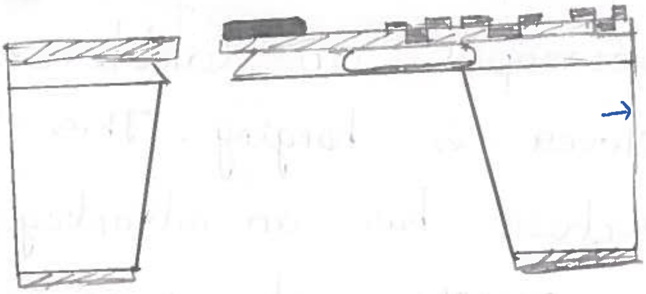


→ On N epi layer P+ layer is formed.

i.e making P+ material i.e silicon resistance versus one metal. i.e two dissimilar materials.



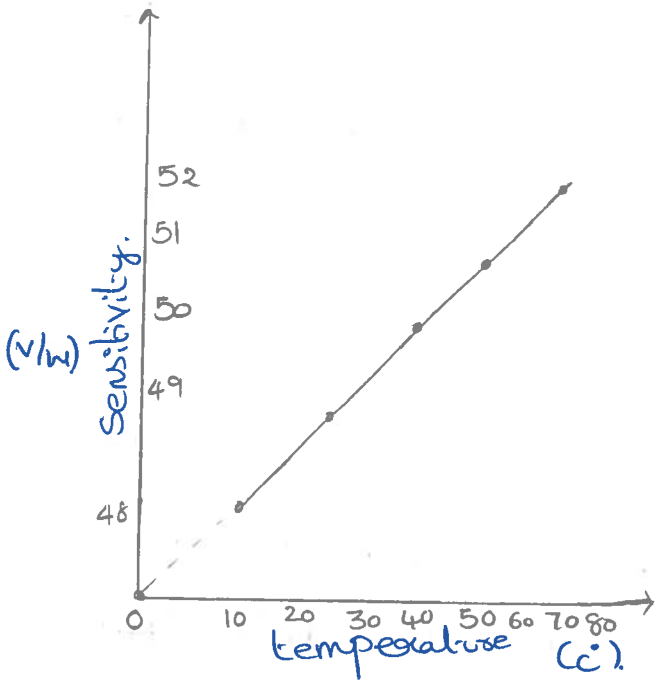
→ One material is silicon material i.e silicon resistance and another metal.
Ex:- Aluminium silicon.

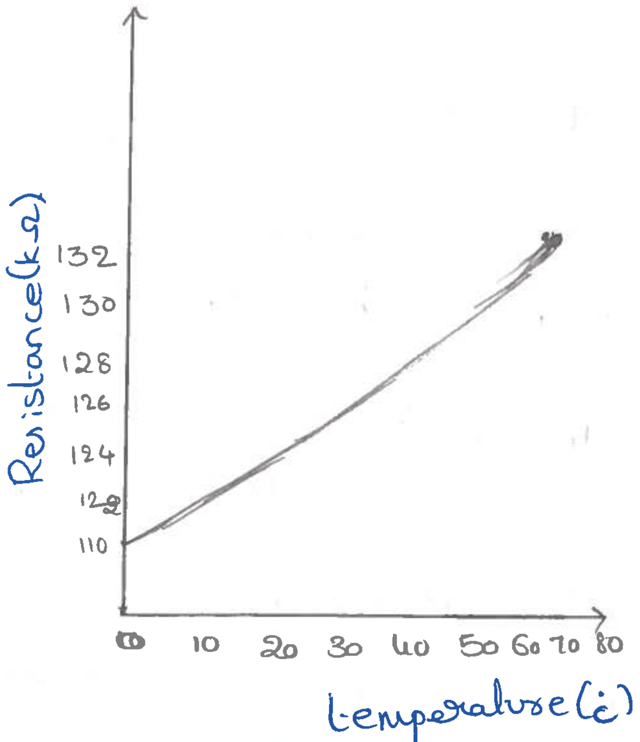


→ After making the contact you go for electro chemical etching. bias dependent electro chemical etching.

due to bias dependent etching window is open here. Silicon nitrate is masking layer. In BSE the top surface is basically protected from electrolyte. So the etching is done from back side.

So in the top the window is open by the KOH etching i.e simple KOH anisotropic etching. Etching on top and bottom gets the Cantilever in the surrounding area. The black region the absorber.





As the temperature increases sensitivity & Resistance increases linearly.

## Bolometer Detector:-

Bolometer detectors are based on the change of resisitivity of a material in response to the heating effect of the incident radiation.

Temperature Coefficient $\alpha = (dR/R\,dT)$.

R is Resistance and T is temperature.

Bolometers Consist of a resistive element Constructed from material with large value of $\alpha$.

**Principle:-** Constant current I is driven through the Bolometer from a regulated current supply. The incident radiation produces a change in $\Delta R$ of the Resistance. The power supply needed to keep the current (I) Constant will adjust the voltage by a small amount $\Delta V$

$$\Delta V = IR\alpha\Delta T$$

There are two types of Bolometer:-

Metal Bolometer:-

Material is a Metal having Positive α (temperature coefficient) such as platinum, gold, nickel, bismuth.

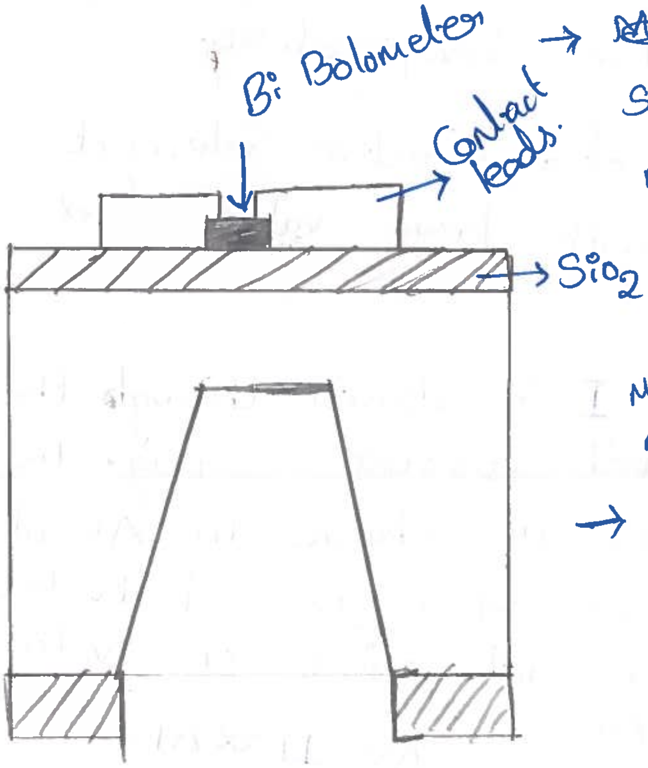
Thermistors:-

Material is a semiconductor having negative α (temperature coefficient) such as a oxidic mixture of manganese, nickel, cobalt, ~~that~~ ~~also will have~~ single crystal semiconductors.

Responsivity of Bolometer is much higher than thermopile detectors

Bolometer detectors are easy to fabricate than Pyroelectric detectors.

Sensing elements can be any nickel, bismuth etc.



→ ~~Mater~~ Silicon dioxide is a Silicon bulk on that an insulated material i.e black portion i.e bismuth Bolometer. and contact leads basically a thin metallic film. resistance.

→ Bismuth of 1000angstrom is deposited and patterned through metal mask.

→ Initially Contact leads are deposited and patterned then in a Vaccum evaporation through holes metal masking is done i.e Bismuth is deposited selectively in a particular portion. (Vaccum mask technique).

The voltage Responsivity of bolometer S(f) is the ratio of ΔV and ΔP

$$S(f) = \frac{\Delta V}{\Delta P} = \frac{\alpha V_b}{G_t(f) + j2\pi f c}$$

$$G_t(f) = G_m(f) + G_a(f)$$

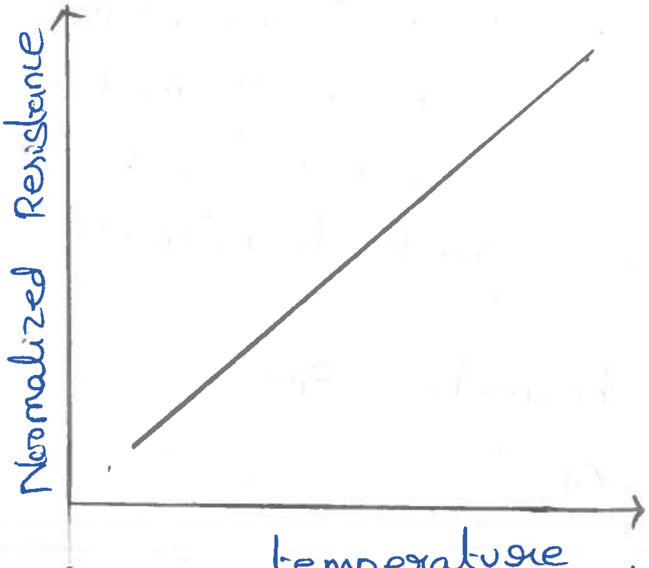
$G_m(f)$ & $G_a(f)$ are thermal Conductance through membrane and Contact leads.

The InfraRed Sensing elements should be:-

a.) As thin as possible
b.) low thermal Conductivity
c.) maximum IR absorptance.

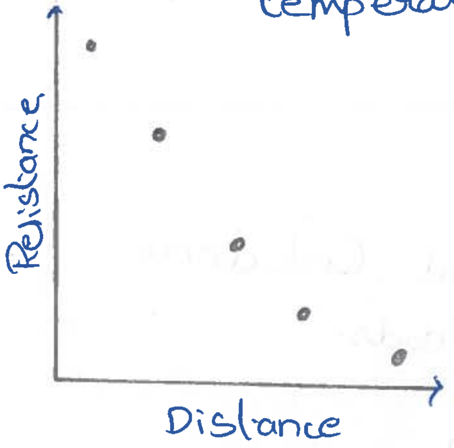
Properties of some Metals used in Bolometer:-

| METAL | Thermal Conductivity | Electrical Conductivity | temperature Coefficient of Resistance ($\alpha$) |
|---|---|---|---|
| Aluminium | 0.5 | 62.9 | 0.0041 |
| Copper | 0.92 | 100 | 0.0039 |
| Gold | 0.72 | 80 | 0.0034 |
| Bismuth | 0.024 | 1.7 | 0.0043 |



As the temperature increases the resistance increases.

temperature ∝ Resistance.



Variation of Bolometer Resistance with Distance from Infrared Source.

Bolometer resistance is found to decrease with IR source distance which means bolometer resistance decreases with IR intensity.

## Pyroelectric Detectors:-

Pyroelectric effect is exhibited in temperature sensitive pyroelectric crystals having internal dipole moment. E.g PZT.

Change of temperature produces changes in the thermal dipole moment so produces a measurable change in surface charge.

Principle :- (irradiated with modulated Radiation).

An alternating temperature $\Delta T$ will rise an alternating charge $\Delta Q$ on the external electrodes $\Delta Q = pA\Delta T$.

p is Pyroelectric coefficient of material (0.4 to $4 \times 10^{8}\,C/cm^{2}K$)

A = the area over whic incident radiation is absorbed.

# Micromachined Mechanical MicroSensors:-

Class of sensors to measure Mechanical phenomena i.e transformation of mechanical signal into electrical signal for display or further electronic treatment.

Four important types of mechanical micro sensors:-

- → Pressure
- → Flow
- → Acceleration
- → Gyro

Applications area :-

- → Process Industry
- → Automotive electronics
- → Medical devices and equipment.
- → Household appliance.

With the increasing safety and Comfort requirements the automotive industry is probably the fastest growing sensor market for applications such as air-bags. active suspension control, antilock brake systems, gas injection and Combustion Control, the pressure monitoring etc.

Read out techniques:-

→Piezoresistive:- These elements are sensitive to the stresses that are induced by the deformation in the microstructure

→ Piezo-Hall :- Sensor is based on the observation that an electric field is developed perpendicular to the current flow to a shear stress

→ Piezo-Junction:- Current gain and $V_{BE}$ depends on the applied stress.

→ Deformation and displacement:-

a.) Capacitive (Capacity)
b.) optical interference

optical interference is the promising for high temperature application.

Capacitive is used in low frequency application as a normal mechanical sensor.

→ Resonant structure:

If stress inside material changes the resonance frequency also changes.
A structure can be either tuning fork, vibrator, Resonator. (change in stress vs Resonance frequency)

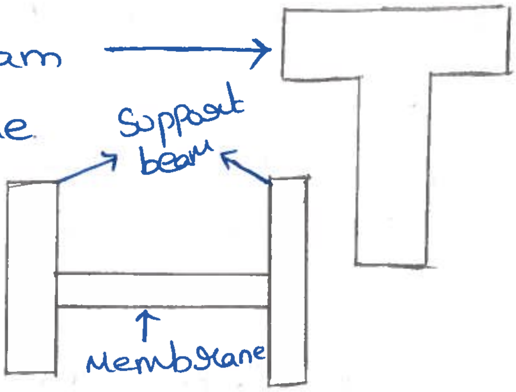
Measurands of Mechanical MicroSensors:-

- → Acceleration / deceleration
- → Force / Torque
- → Pressure / stress
- → Flow rate
- → Position / angle
- → Displacement

## Micromechanical structures used in mechanical Sensors:-

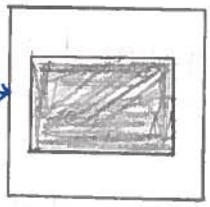
→ Cantilever beam

→ Bridge/Flexure



→ Diaphragm

→ Membrane.



A membrane is formed by tension

A diaphragm is formed by ~~elasti~~ Stiffness.

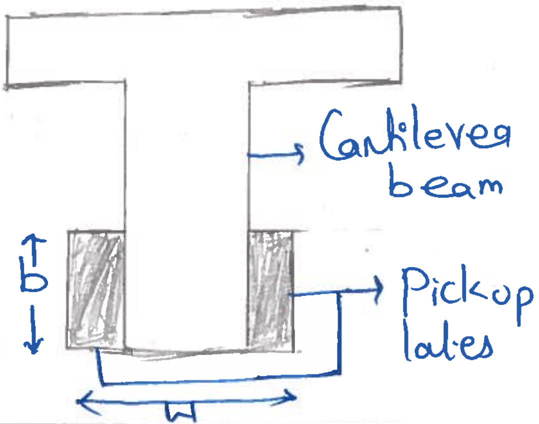
If a structure exhibits elasticity then it is known as ~~dia~~ diaphragm.

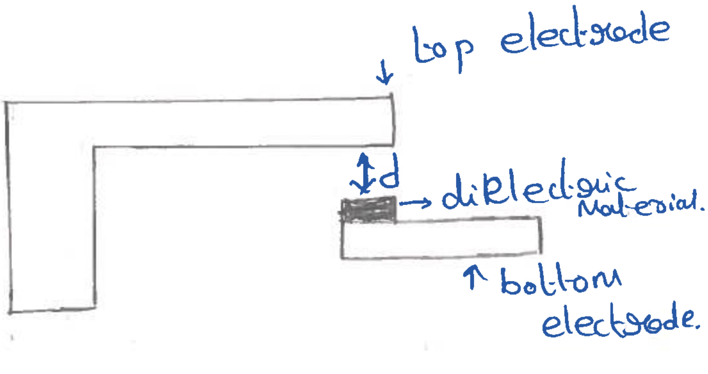
all the four are the Common microstructures which are used in different kinds of microsensors

## Different ways of defection:-

→ Capacitive (electrostatic) Pick up
→ Resistive (Conductive) Pick up
→ Inductive (amperometric) Pick up

## Capacitive Measurement of the Deflection of a Simple Cantilever beam:-





The deflection is Converted into Capacitance change. one electrode is placed at top and one electrode is placed at bottom. In between there is a dielectric.

Capacitance value depends on:-

1) dielectric thickness, gap b/w the top and bottom electrode (d).
2.) Dielectric permittivity (ε)
3.) Overlapping Area (A).

In one Condition:-

If there is any stress Cantilever beam vibrates top and bottom then the gap between top and bottom electrode will change.

2nd Condition:-

Cantilever beam is fixed. if pickup plates moves in lateral direction then there is a overlap in area. (i.e overlap area b/w top and bottom electrodes changes).

gap between top and bottom electrode doesnot change.

Dielectric permittivity does not change (ε).

## Piezoresistive Measurement of the Deflection of a Simple Cantilever Beam:-

Bridge has 2 support beam. which has a thin Cantilever in middle of support beam. one end will have a proof mask. one end will have piezoresistor which is highly sensitive location.

The movement of proof mask vertically top and bottom then there will be a bend which leads to stress ∴ piezoresistance will change and measure resistance values.

So in order to find out voltage we go for wheatstone-bridge.

Doped silicon Resistance are fabricated. As silicon is well established material in Integrated Circuits so the cost will be less.

Silicon has a strain gage factor kgf which is higher than of metal the range is of 50 to 100. strain gage factor is metal is nearly 2. kgf defines sensitivity i.e. ratio of change in Resistance to the mechanical strain km.

$$\frac{\Delta R}{R\,k_m} = kgf.$$

## Silicon Crystal as piezoresistive Material:-

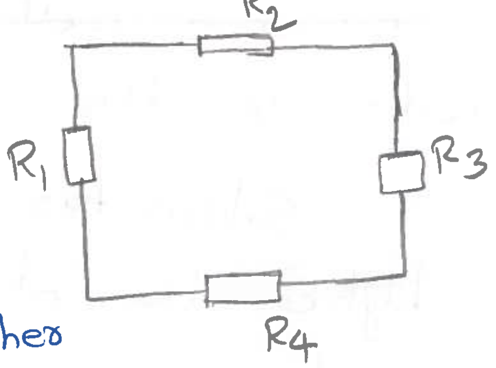
Silicon is highly used for conversion of mechanical deformation to an electrical signal and is used as basic material for piezoresistive sensors. for mechanical signals such as pressure flow force and acceleration.

Silicon piezoresistive sensors show better Performance compared with classical metal strain gauges.

- Silicon is very robust material.
- Good matching of resistors can be achieved which is Particularly useful in wheat-stone bridge.
- Silicon is very suitable for miniaturization of sensors
- Signal amplification and temperature compensation circuitry can easily be integrated on the sensor chip.

## Position of Four piezoresistors:-

In membrane 2 piezo-resistor can be placed parallel to opposite edges of the membrane and the other two perpendicular to the other 2 edges.

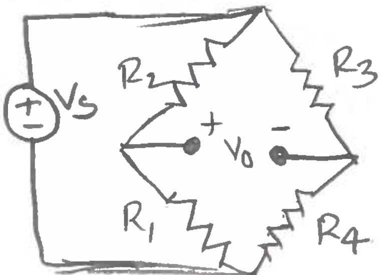


The change of resistance in first 2 piezo resistors will always be opposite to that of the other two.

When membrane is bent downwards. Causing stress the parallel resistors are under lateral stress and show a decrease in resistance and perpendicular resistors are under longitudinal stress and show an increase in resistance.

The differential output voltage $(\Delta V)$ is $\Delta V = \frac{\Delta R}{R} V_s$.

R= zero stress resistance.



$$R_1 = R_3 = (1+\alpha_1)R_0 \qquad R_2 = R_4 = (1-\alpha_2)R_0$$

$$\frac{V_o}{V_s} = \frac{R_1R_3 - R_2R_4}{(R_1+R_2)(R_3+R_4)} = \frac{2(\alpha_1+\alpha_2)}{1+\alpha_1-\alpha_2}.$$

$$\text{Sensitivity} = \frac{\Delta V}{\Delta P\, V_s} = \frac{\Delta R}{\Delta P\, R}.$$

# Micromachined Pressure Sensors:-

## Pressure Ranges for Various Applications:-

| Application | Pressure Range(KPa) |
|---|---|
| Manifold pressure | 0-105 |
| Barometric " | 50-105 |
| Exhaust gas re-circulation | 0 -105 |
| Fuel Pressure | 0 - 105 |
| Tyre Pressure | 234-500 |
| Active suspension hydraulics | 20000 |
| climate Control | 50- 105 |

Pressure sensors are the first type of silicon micromachined sensors to be developed in the late 1950's and early 1960's.

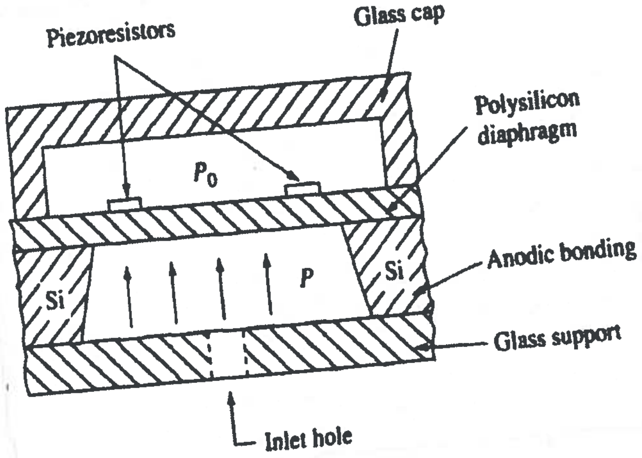
The largest market is undoubtedly the automotive. ~~silicon~~

The two most important silicon sensors are pressure sensors and microaccelerometer sensors with substantial growth expected for gyrometers used in navigation.

| Year | Revenue (MEuro) | Growth rate(%) |
|---|---|---|
| 1989 | 175 | - |
| 1990 | 283 | 62 |
| 1994 | 312 | 10 |
| 1997 | 564 | 22 |
| 1998 | 679 | 20 |
| 1999 | 804·2 | 18 |

The most two common methods to fabricate pressure microsensors are bulk and surface micromachining of poly silicon.

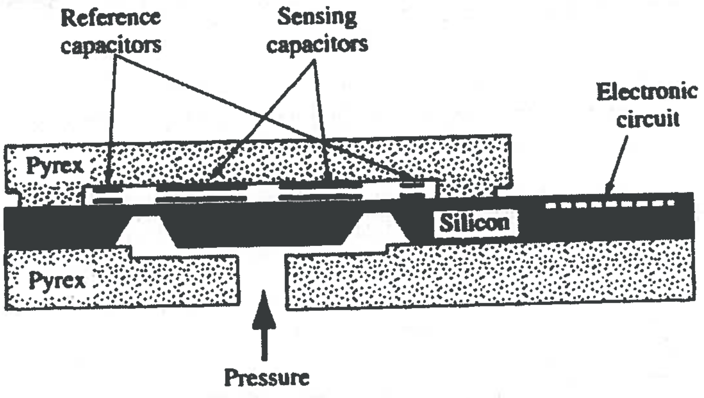
The 2 kinds of possible mechanics of the pressure sensing are:- 1.) Piezoresistive
2.) Capacitive.



The deflection in the diaphragm can be measured using piezoresistive strain gauges located in the appropriate region of maximum strain. strain gauges are made use of doped silicon and are designed with a read out circuit such as wheat stone bridge.

The change in strain can be related to the applied pressure $(P-P_0)$. The precise relation depends on the relative piezoresistive coefficient $\pi$ (diaphragm material).

$$V_{out} \propto \Delta R \propto \pi(P-P_0).$$



This figure shows the general arrangement of a single crystal silicon pressure sensor with capacitive pickup. A capacitive bridge with two reference capacitors and the output voltage is related to the deflection of the membrane $\Delta x$ and pressure $P-P_0$

$V_{out} \propto \Delta C \propto \Delta x \propto (P - P_o)$.

$P_o$ is Background pressure.

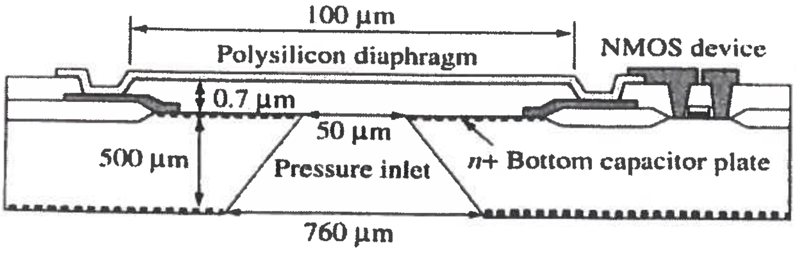
- → An absolute pressure sensor that is referred to a Vaccum ($P_o = 0$).
- → A gauge type pressure Sensor that is referenced to atmospheric pressure ($P_o = 1$ atm).
- → A differential or relative type ($P_o$ is Constant).

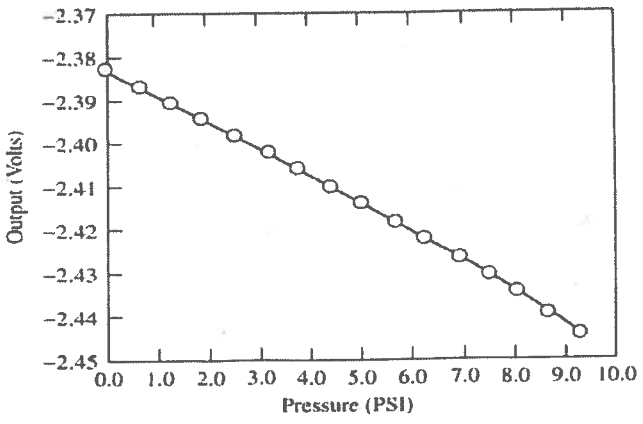
The main Advantage of Bulk micromachining is that the electronic circuit Can be more readily integrated.

Pressure Sensor achieves a high resolution by using integrated Circuits. (Kung and Lee 1992).

An alternative approach to enhance the sensitivity of Silicon pressure sensors was Proposed by Greenwood in 1988 and Comprised the use of a resonant microstructure.

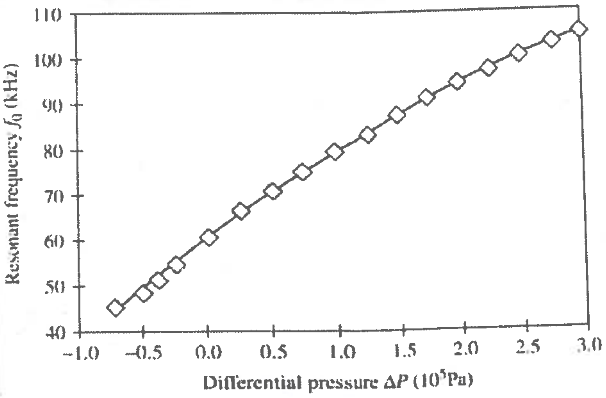
The basic principle is the change of resonant frequency of oscillation of this structure when the pressure on the diaphragm Causes it to curve.





| Tyepe | Advantages | Disadvantages |
|---|---|---|
| Capacitive | More Sensitive<br>less temperature sensitive<br>More robust | large piece of silicon for bulk micromachining<br>Electronically more complicated.<br>Needs integrated electronics. |
| Piezoresistive | Smaller structure than bulk Capacitance<br>simple transducer circuit<br>No need for integration. | Strong temperature dependance.<br>piezo coefficient depends on doping level. |

Resonant pressure sensor have excellent resolution and stability through the running of resonator in a Partial Vaccum. It can achieve high mechanical Q factor i.e 18000 at a pressure of approximately 1 Pa. The Response is as shown.



As the differential pressure ($\Delta P$) increases Resonant frequency ($f_0$) increases.

$\therefore \quad \Delta P \propto f_0.$

The microstructure behaves as a non linear resonator.

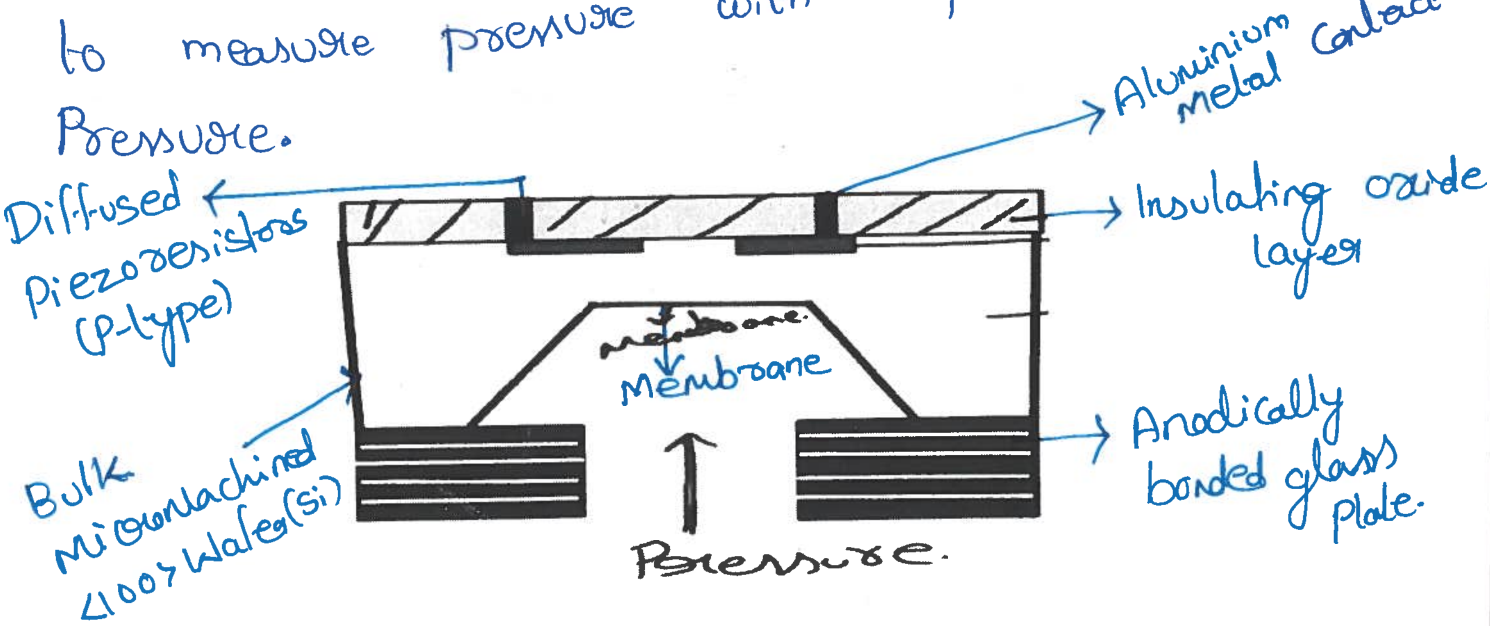
Fabrication Process:- Fabrication of a piezoresistive pressure sensor. (Bulk micromachined).

On diffused silicon layer we have diffused p-type resistors and then an insulating oxide layer.

There will be a metal contact which is of aluminium metal with the diffused p-type resistors.

Bulk silicon have diffused p-type resistors and the surface is etched by 100 anisotropic etching from the bottom. which is anodically bonded with that bottom glass plate containing a hole. So that their will be a contact of ambient with the membrane.

This kind of structures are used to measure pressure with respect to atmospheric Pressure.



# Flow Micro Sensors:-

The measurement of the flow rate of a gas or liquid is important in a number of different fields from automotive and aerospace to the chemical industries.

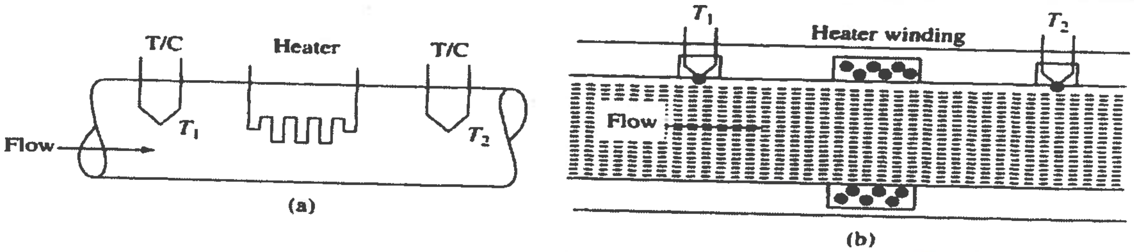
Ex:- It is important to know the amount of fuel flowing into an engine.

Domestic gas supplied to boilers in homes.

There are number of traditional ways to measure flow directly and indirectly through the differential Pressure.

One possible method is to use an ultrasonic technique such as a SAW device.

The most commonly used principle to detect flow in gases and liquids using micro-sensors is based on the concept of a thermal flow sensor that was assumed by Thomas in 1911.



(a)

(b)

The heat transferred per unit time ($P_h$) from a resistive wire heater to a moving liquid is monitored at two points via thermocouple temperature sensors.

When steady state has been achieved the mass flow rate $Q_m$ is related to difference in the temperature $(T_2-T_1)$ given by.

$$Q_M = \frac{dm}{dt} = \frac{P_h}{C_m}(T_2-T_1)$$

$P_h$: heat transferred by unit time.

$C_m$: specific heat capacity of the fluid.

if there is heat loss from the wall of the tube. The mass flow rate of the liquid can be converted to the volumetric flow rate $Q_V$ via density $P_m$:

$$Q_V = \frac{dv}{dt} = \frac{Q_M}{P_M}.$$

The placing of the heating coil and temperature sensors with in the wall of a pipe makes more practical sense and the embodiment is so-called boundary-layer version. (fig 2).

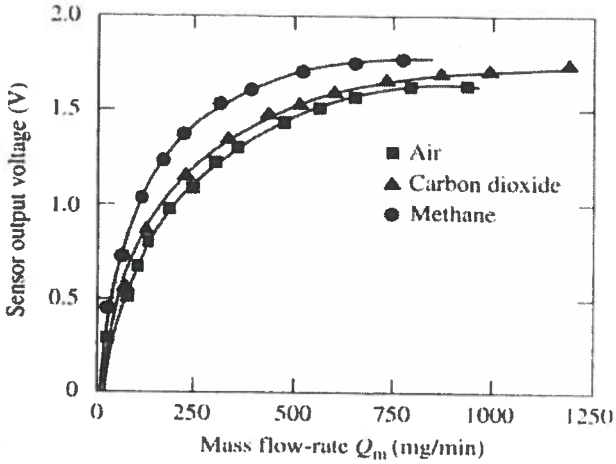
A number of different silicon micromachined flow sensors have been reported since the late 1980's. Johnson and Higashi reported in 1987 on the use of bulk micromachining to make a pair of silicon microbridges.

There is a thermistor on top of each bridge and a resistive heater is split between the two.

The silicon microbridge is advantageous because it is thermally isolated and power loss of heater is minimised.

In this case 1mW of power produce a 15°C rise in temperature in a gas.

The temperature difference is measured in a wheatstone bridge and the output voltage is shown in fig (3) for air, Carbonmonoxide and methane.



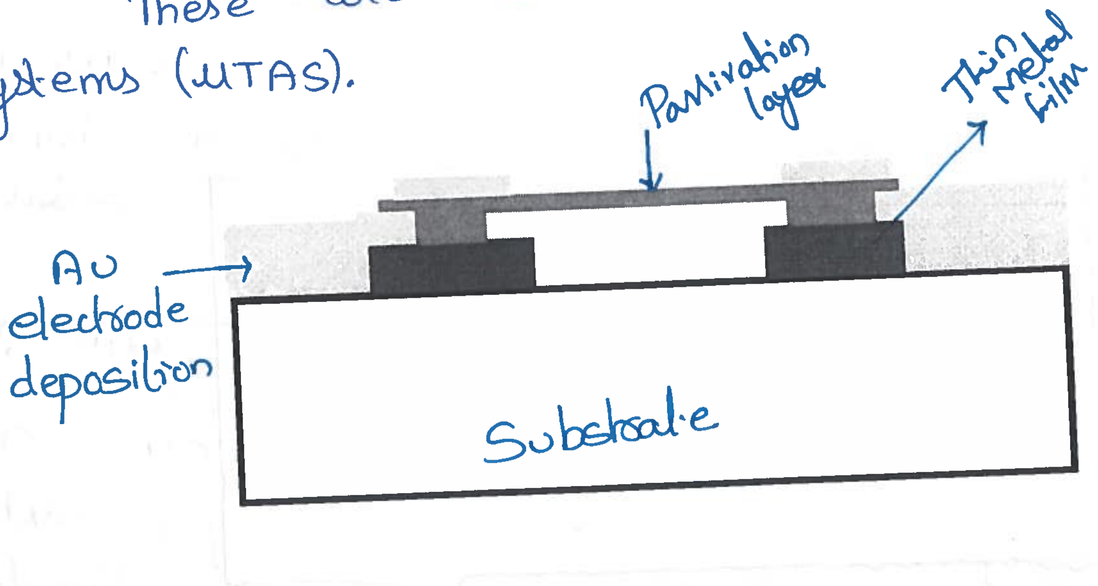
The device can be used to measure flow velocities of upto 30 m/s in a 5µm by 250µm channel. The mass flow is related to the velocity v.

$$Q_m = \rho_m A v.$$

In a slightly different approach Stemme (1986) replaced the microbridge by a cantilever beam and incorporated a layer of polymide to help thermally isolate the heater from the substrate. Thermistors are replaced by thermodiodes and the sensor has CMOS integrated circuit. Flow velocities of up to 30 m/s can again be measured but this time with about half power consumption.

The applications of silicon flow sensor is likely to increase significantly over the next few years because of the growing importance of the field of microfluidics in MEMS.

These are referred as micro total analysis systems ($\mu$TAS).



Fabrication process:-

The fabrication technique here used in lift off method from lithography.

1.) $SiO_2$ wafer is cleaned with accetone
2.) $SiO_2$ is Covered with Photo Resist by using spin Coat method.
3.) Exposed to UV rays deposition of thin metal by masking.
4.) After deposition of thin metal film sample is lifted off (Resist stripping).
5.) Electrodes made of Au are are Connected with sensor (thin Metal film).
6.) A Passivation layer is deposited on top in order to avoid Corrision and fluid environment.

# MEMS Inertial Sensors:-

Micromachined inertial sensors consisting of accelerometers and gyroscopes, are one of the important types of silicon based sensors.

Microaccelerometers alone have the second largest sales volume after pressure sensors and it is believed to be that gyro's will soon be mass produced at similar volumes.

The large volume demand for accelerometer is due to their automotive applications where they are used to activate safety systems and electronic suspension.

Microaccelerometer for measuring rate of acceleration, velocity, displacement vectors.

Micromachined Gyro's for measuring rate of Rotation rate, axis, angle.

The application areas are automobile
Aerospace
Missile
Robotics.

Biomedical medical application for activity tracking.

Tracking and monitoring mechanical shock and vibration during transport and handling of a variety of equipment and goods.

Consumer applications:-

→ Active stabilization of picture in Camcorders.

→ Three-dimensional mouse

→ Sports-equipment.

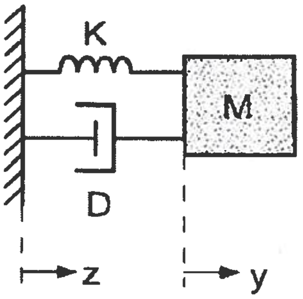
| Type | Range | Application Area. |
|---|---|---|
| Acceleration Sensor | ±1g | Antilock Breaking system(ABS)<br>VR(virtual Reality)<br>Tracks and Control system. |
| | ±2g | Vertical body motion |
| | ±50g | Front Airbag deployment<br>wheel motion.<br>Active suspension. |
| | 100 to 250g | Side Airbag deployment. |
| Shock Survivability | 500g | Powered all axis. |
| Temperature Range | -40 to 85°c | Operation Condition. |
| | -55 to 85°c | Storage Condition. |

The main markets of microaccelerometers are in automatic Breaking system and suspension system (0 to 2g) and air bag systems (up to 50g). The market today is worth ranging from 200 to €300M in the United States alone.

As the market has been increased unit price has fallen from €100 to €9 during this Period.

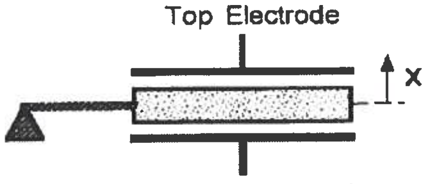
| Application | 1991 | 1993 | 1996 | 2000 |
|---|---|---|---|---|
| Air bag | 21 | 89 | 127 | 135 |
| ABS | 0 | 8 | 31 | 56 |
| Suspension | 0 | 13 | 19 | 22 |
| Total | 21 | 110 | 177 | 213 |

Market of Microaccelero
meters in
Million Euros



## Micromachined Accelerometers:-

An accelerometer generally Consists of proof-mass suspended by complaint beams anchored to a fixed frame.



Relative Mass Displacement = x= y-z

Proof mass has a Mass M suspension beams have an effective spring Constant K and a damping factor (D). Which affects the dynamic movement of mass.

External acceleration displaces the support frame relative to proof mass which relative changes the internal stress in the suspension string(spring). Both relative displacement and the suspension beam stress used to measure the external acceleration.

Parameters:- Sensitivity, maximum operation range, frequency response, resolution, full scale nonlinearity, offset, off-axis sensitivity and shock survival

## Typical Specifications:-

| Parameter | Automotive | Navigation<br>~~Navigagd~~ |
|---|---|---|
| Range | ±50g (airbag)<br>±2g (vehicle stability) | ±1g |
| Frequency range | DC-400HZ | DC-100Hz |
| Resolution | <100mg (airbag)<br><10mg (vehicle stability) | <4μg |
| off axis sensitivity | <5% | <0.1% |
| Non linearity | <2% | <0.1% |
| Max shock Range in 1msec | >2000g | >10g |
| temp Range | -40°c to 85°c | -40°c to 80°c |

## Devices Types:-

Piezoresistive Devices:- First micromachined and first commercialised microaccelerometers were piezoresistive. The accelerometers incorporate silicon piezoresistors in their suspension beam. As the supportive frame moves relative proof mass the suspension beams will elongate or shorten which changes their stress profile which leads to change in resistance. The resistors are placed at the edge of support beam and proof mass. half or full bridge can be formed by employin two or four Piezoresistors.

Resonant Devices:- (Quartz Micromachining).

The main advantage of resonant sensors is their direct digital output.

The devices can be of RL, LC or RLC. if we consider ~~RL~~ LC i.e a reactive parameter either L or C change. The resonance frequency also changes.

let the variation of capacitance which may be connected ~~is~~ with accelerometer structure, which makes an oscillator whose frequency oscillation changes with respect to movement of the proof mass.

Thermal devices:-

Accelerometers based on Thermal transduction.

Principle:- temperature flux from a heater to heat sink plate is inversely proportional to their Seperation.

Hence by measuring temperature using thermopiles, the change in seperation between the plates can be measured.

It uses both bulk and surface micromaching for fabrication.

The main advantage of piezoresistive accelerometers is the simplicity of their structure and fabrication process.

## Capacitive Devices:-

In the presence of external acceleration the support frame of an accelerometer moves from it's rest position thus change in capacitance occurs between proof mass and a fixed conductive electrode seperated with a narrow gap. Capacitance measured by electronic circuitry.

This capacitive devices uses Bulk Micromachining process.

## Tunneling Devices:-

High resolution physical sensors including accelerometers use a constant tunneling current between one tunneling tip and it's counter electrode to sense displacement.

When the tip is brough soffeciently close to it's counter electrode using electrostatic force generated by bottom deflection electrode. a tunneling current is established ($I_{tun}$) and remain constant if the tunneling voltage ($V_{tun}$) and distance between the tip and counter electrode are unchanged.

Technology:-

- → Surface Micromachining
- → Electro forming (LIGA)
- → Mixed Process
- → Bulk Micromachining.

## Micromachined Gyroscopes:-

Almost all micromachined gyroscopes use vibrating mechanical elements to sense rotation.

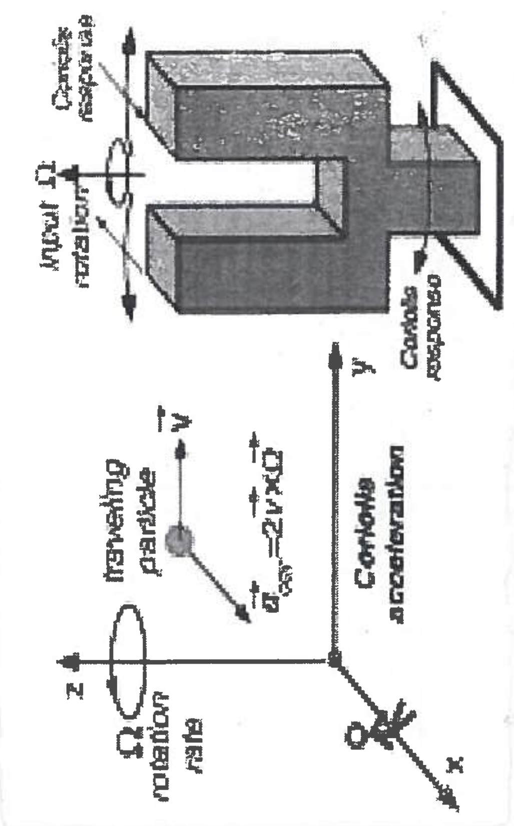
They don't have any rotating parts like bearings and hence they can easily be miniaturized and batch fabricated using micromachining.

All Vibratory Gyroscopes are based on the transfer of energy between two vibration modes of a structure. Caused by Coriolis acceleration.

Coriolis acceleration named after the french scientist and engineer G.G.de Coriolis.

Imagine a particle traveling with a velocity vector v.

An observer sitting on x-axis of the xyz coordinate system as shown in fig. watching the particle.



If the Coordinate system along with the observer starting rotating around the z-axis with an angular velocity $\Omega$. the an observer thinks the particle is changing its trajectory towards with x-axis with acceleration equal to $2V \times \Omega$. Although No force has been exerted on the Particle.

Force ∝ rotation rate.

This is the basic operation underlying in all Vibratory structure gyroscopes.

The first silicon Coupled resonator gyrometer was developed by drapper (1993).

(For diagram Refer end of the topic)

(Micromachined GyroScope)

The device is bulk micromachined and supported by torsional beams with micromass made from doped Single Crystal silicon.

The outer gimbal was driven electrostatically at a Constant amplitude and the inner gimbal motion was sensed.

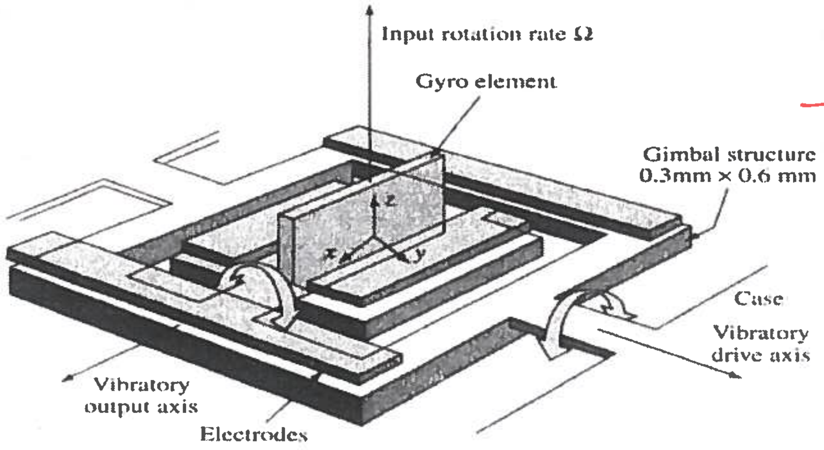
More advanced gyroscopes have been fabricated Using Surface micromachining. of polysilicon. (Geiger 1998).

| Parameter | specification |
|---|---|
| Bias stability | $0.018\ \mathrm{deg}\ s^{-1}$ |
| Noise | $0.27\ \mathrm{deg}/h$ |
| Sensitivity | $10\ \mathrm{mV}/(\mathrm{deg}\ s^{-1})$ |
| linearity | $<0.2\%$ |
| Supply Voltage | 15V |
| Current | 20mA |
| Shock Survival | 1000g. |

MARS-
RRI
by
Geiger (1998)

Another is ring Gyroscope works by Coriolis force transferring energy from one mode into another at 45° by Ayazi and Najifi 1998.

There is a Considerable interest in Silicon gyroscopes in the defense industries for Controlling missiles. but low-cost Commercial devices for non military are appearing Now ie automobile applications (automotive).



→ Micromachined Gyroscope
Bulk Micromachining