MEMS & Microsystems
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Lecture No. # 17
Micromachined Microsensors Mechanical

The last lecture I discussed on micromachined microsensors thermal. Today's lecture I will just highlight micromachined microsensors mechanical. That means how the mechanical energy is translated into the electrical energy and how that electrical energy is picked up. That is the basis of the micromachined microsensors mechanical and I remember in lecture number 2 or 3. I discussed on sensors, its measurands and there I explained on mechanical microsensors. What kind of measurands are there in mechanical microsensor, Ihope all of you know.So now those measurands I have to convert into some electrical signal either resistance change or voltage change or capacitance change or current change whatever it is, so that the next part I can process, those signals for some kind of actuation.

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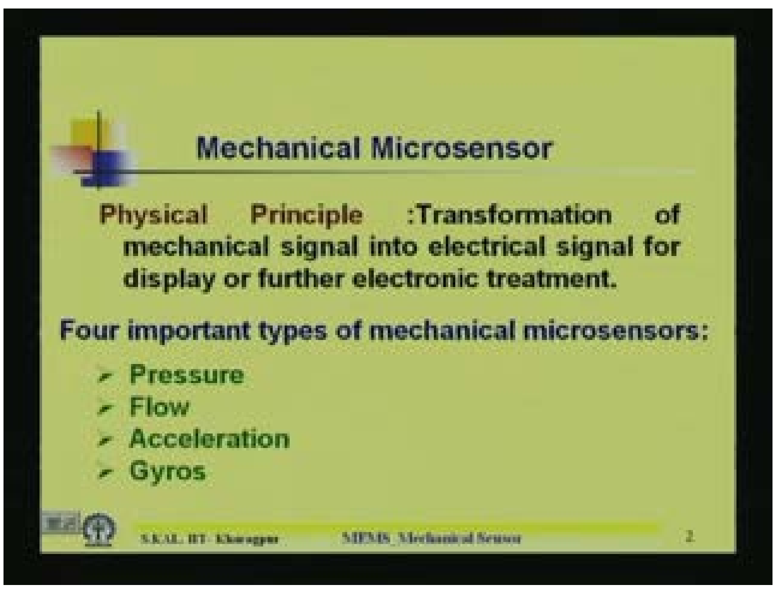

So now the mechanical microsensors its physical principle, is transformation of mechanical signal into electrical signal for display or further electronic treatment. That further electronic treatment is basically the signal processing. So that is the basic principle. Four important types of mechanical microsensors will be discussed in this courseand those sensors are pressure, flow, acceleration, gyros.Gyro is a rotation sensor. In today's lecture I will discuss in detail on the pressure sensorsand acceleration gyro and flow sensors we will be discussed at a later stage in some other lectures.

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Now the application areas of mechanical microsensors are given here.Primary application areas are process industry, automotive electronics, medical devices and equipment, household appliance. These are major application areas of mechanical microsensors.With the increase of 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, tire pressure monitoring and others.The mechanical microsensors major use and application is in automobile sectors. For application in air bag suspension, antilock breaking system which is known as abs microsensor, injection and combustion control of the fuel and tire pressure. So there the sensors are various types, not the pressure sensor is using. In some case you will acceleration sensors. Some case pressure sensors, some case you need the rotation sensors also. So the major thrust of the mechanical microsensors is with respect to the automobile application.

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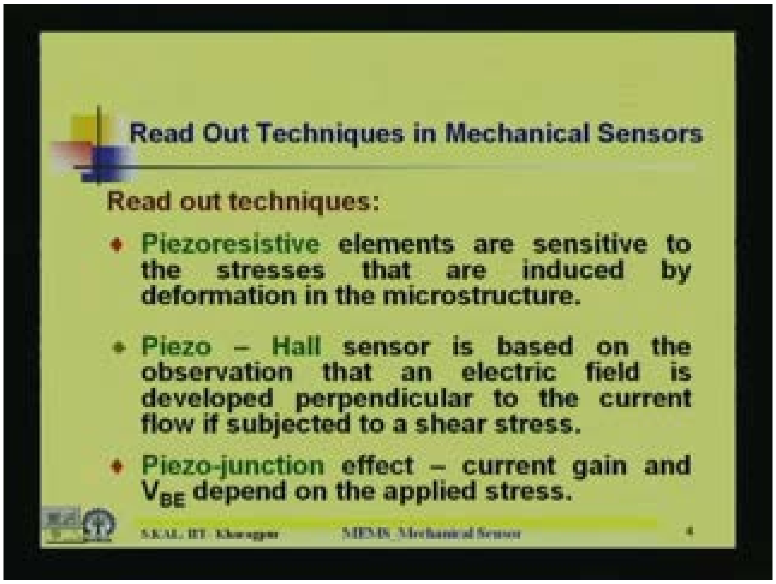

Now what are the read out techniques in mechanical sensors? Those are piezoresistive read out technique,piezo-hall read out technique,piezo-junction read out techniques. What are those effects? Piezoresistive elements you know are sensitive to the stresses that are induced by deformation in the microstructure. Deformation of the microstructure is mechanical phenomenon and mechanical energy change. That means deformation hall, the material will be deformed by application of thrust by application of jerk by vibrating the module. That is the deformation and because of that, the stresses will be there and because of that stress, if you apply a stress sensitive element which is the piezoresistance, then automatically the change of resistance can be converted into the change of voltage or current. So easily you can pick up the signal that is one readout technique.

Second one is piezo-hall that is based on the observation that an electric filed is developed perpendicular to the current flow is subjected to a shear stress. Current is flowing through a sensor element. Now if we apply stress an electric field normally to the direction of current to will change and that is basically the hall-effect. Isn't it? So when that hall-effect is basically there one magnetic field is hall measurement said you know that is the magnetic field there. But here there is not magnetic field; it is knownpiezo-hall. Piezo-hall means voltage and current perpendicular direction is changing with the application ofnon-magnetic field, with the application of the pressurethat means stress. That is why isin semiconductor physics, the hall-effect what you have started not the same kind. But similar kind of effect you can see in some of the materials where you can see the piezo-hall by application of pressure the voltage will appear perpendicular to the current direction.

That is the piezo-hall effect. That effect is sometime used for the pick-up electronic read out technique. Now third one is piezo-junction effect. Here current gain and VBE depends on the applied stress. VBE is basically base emitter voltage of the junction or transistor base emitter junction or PN junction. The cutting voltage which we call it is that voltage as well as the beta current gain of the transistor changes with the application of the stress inside the silicon material.

When that effect is utilized, that is known piezo-junction effect change of the VBE as well as beta. We have seen the change of VBE and beta with respect to temperature. In your circuit class biasing of the circuit is necessary because of that thermal stability, biased thermal stability. But here you will come across a different phenomenon which is known as piezo-junction effect. That is basically the change of the VBE as well as beta with stress produced inside the semiconductor material.

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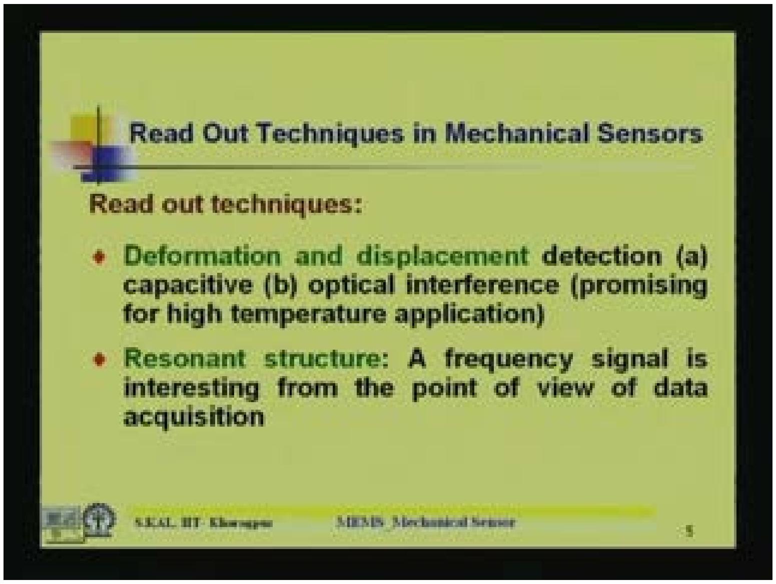

So the read out techniques continuation, other than these three are also available and those read out techniques are resonance, structure, deformation and displacement.Deformation and displacement detection and that deformation and displacement detection one is the capacity, another is the optical inference. Optical inference is the promising for high temperature application and capacity is used even inlow frequency application and normal mechanical sensor use the capacitive change that is deformation and displacement. If something is deformed, the capacitance changes. That is basically not the prop inherent property of the material. In earlier three creation cases whether it is a piezo-hall or is a piezoresistive effect or the piezo-junction that is the material property. But here the physical change is an external capacitance. If you can make parallel plate capacitance here one plate is deformed. So obviously capacitance is going to change. So that is not internal property of the material. But the external the fabricated capacitance value is going to change due to the deformation and displacement of the microstructure.That may be usedand optical interference is also an important phenomenon which is used in MOEMS.

MOEMS auto electromechanical sensors, there this particular effect is used and that effect is not going to modulator change in high temperature application. So that is another advantage of this particular effect optical interference. Then height the temperature will modify that piezo-junction effect temperature may modify the piezoresistance effect. But if you use the capacity or optical interference phenomenon in a sensing read out circuitry. So those there insensitive to temperature variation, that is one advantage. Thermal noise will not be there. Clear. Will not affect this sensor signal output. That has got advantage over others piezo-hall or piezo-junction or piezorresistive phenomenon. Now another important the read out technique is a resonant structure a frequency signal is interesting from the point of view of data acquisition. You see in some case of mechanical sensors, we can sense the mechanical signal with the change of frequency. Frequency change is also electrical. Electrical measurement I can say change of frequency.

So if I make a resonator and because of the vibration or deformation of the structure, if the resonance frequency of the structure is changed, so that change of resonance frequency may be measure of the measurement. Isn’t it? So that is that particular the frequency change of the structure and is sometimes you know the piezoelectric material quartz lithium niobate. Those materials may be used for this kind of the read out techniques. A resonance structure you have to make either the tuning fork kind of thing or you may simply the vibrator or resonator you can make out of the material by micromachining and those things we will alsofrequency will change by deformation. If you apply stress inside the material so because of stress change the resonance frequency be also change and if you pick-up that resonance change and there is a relation between stress change stress versus resonance frequency and that kind of thing you can use for making this mechanical sensor. So now these are the read various kinds of read out techniques used in mechanical sensors.

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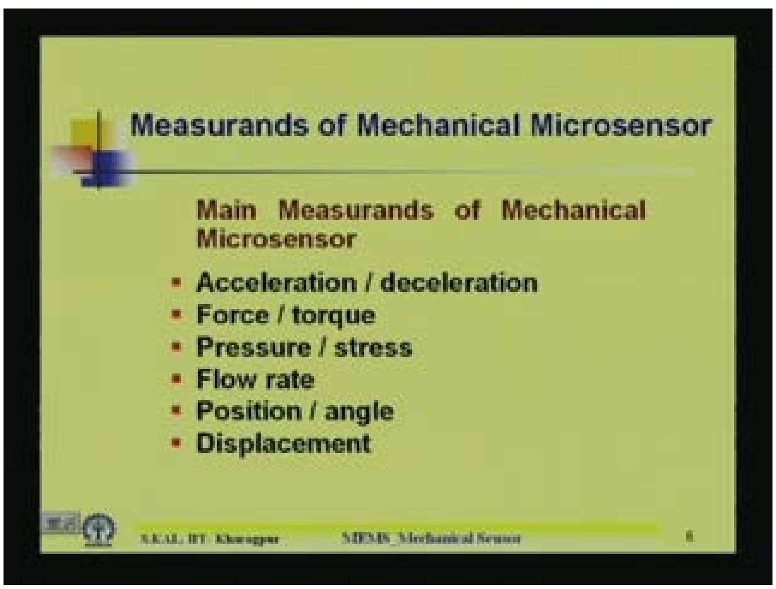

Now what are the main measurands of mechanical microsensor?The main measurands of mechanical microsensor are acceleration, deceleration, force, torque, pressure, stress. Similar kinds of things are written with stroke. Flow rate, flow of fluid may be air may be liquid. Flow of fluid is also some mechanical phenomenon, position and angle detection by change of the structure deformation position of the some sensory element may change that position or angle, displacement. Those are basically the measurands of mechanical microsensor and when we sense the acceleration deceleration that is known as accelerometerforce and torque that we call it sometimes force or torque pressure sensor also is called pressure or stress change is also pressure sensor, flow rate change in which sense that is known as a flow sensor. Position detector when the angle or rotation change is that is known as gyro sensor. So these kinds of sensors are available depending on which measurands are detected in those kinds of sensors.

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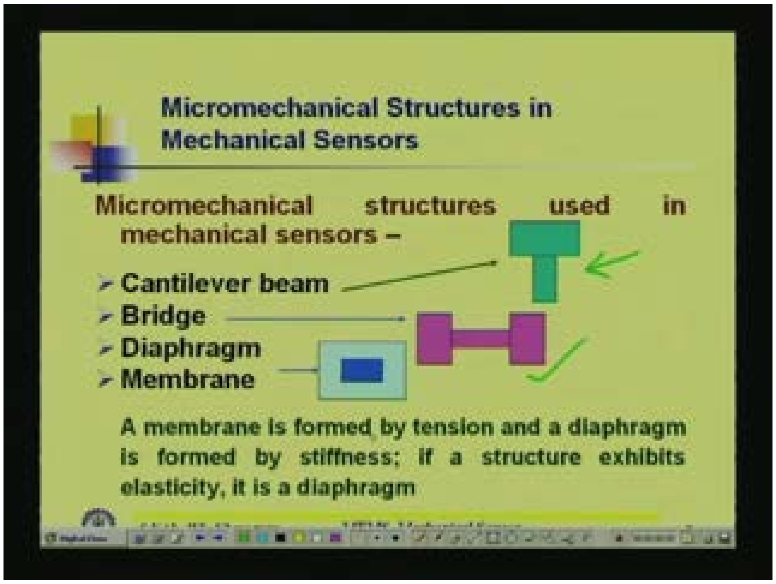

Now what are the mechanical structures used in mechanical sensor? Already most of the structures you are familiar. Cantilever is shown here and the cantilever structure has got many applications in case of mechanical structures. Then there is a bridge, this is a bridge or it is sometimes called flexure. That means the two support beam is there and in between there is a thin membrane. When the supported by the two frame, then it is known as bridge. Third structure is diaphragm on membrane. Diaphragm and membranes are similar, but not exactly same. So for mechanical structure point of view, there is a small difference between a diaphragm and membrane. What are those differences? A membrane is formed by tension and a diaphragm is formed by stiffness. So we have to know what is the difference between tension and stiffness? So there is another difference, if a structure exhibits elasticity, it is a diaphragm. But in membrane the elasticity property is not considered although by appearance both are almost same. But from mechanical properties point of view, there is a slight difference between a diaphragm and a membrane. The diaphragm and membrane,bridge and cantilever are the common microstructures which are used in different kinds of microsensors.

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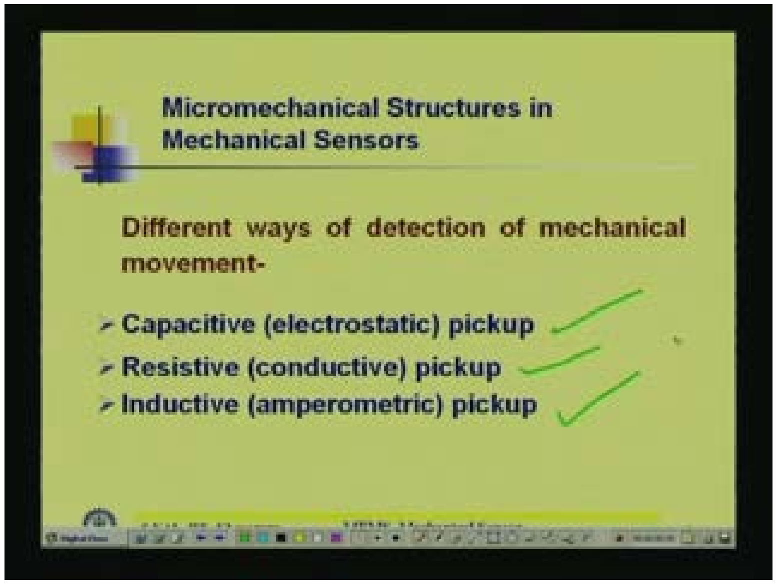

Now detection of mechanical moment as I mentioned, the readout techniques one is a capacitive pick-up, a resistive capacitive pickup is this one. A resistive or conductive pick-up of oppose each opposite of resistance changes or conductor change. So resistive or conductive pickup inductive, this is sometime call is amperometric pickup that will change of current. When change of current by certain technique, we can pick up the current change that is known as an inductive pickup. So capacitive resistive inductive all these three pickups are used in depending on your application, depending in your basic principle of operation of the mechanical sensors.

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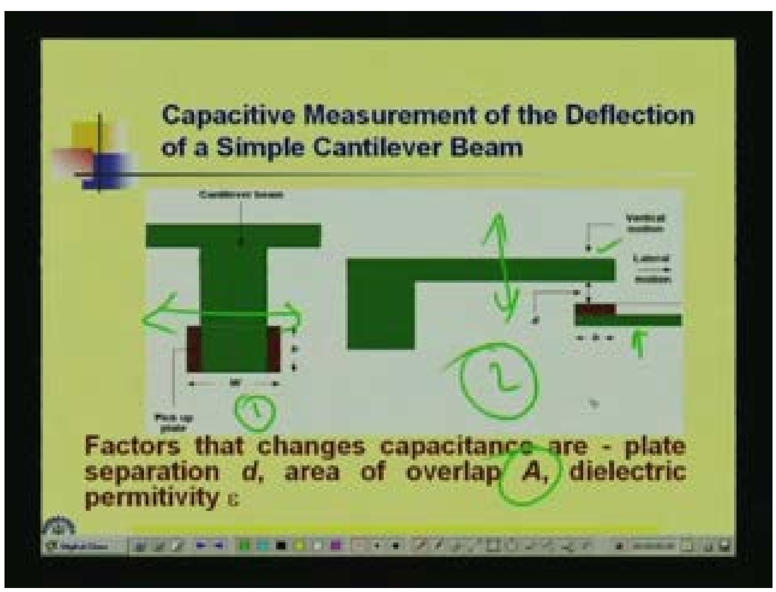

Now here are some examples. Capacitive measurement of the deflection of the sample cantilever, simple cantilever beam. This is the simple cantilever beam which is shown here. This is the cantilever beam structure, one here another is a cantilever beam here. So now how it is basically deflection is converted into capacitance change. In this kind of structure you can see in both cases this is one and this is a second case. In both the cases the parallel plate capacitance is use has been fabricated here. Here is the one electrode, top electrode. This is the bottom electrode and in between bottom electrode is here and top electrode is here. In between there is dielectric, the dielectric is here you can see the air gap. That means the capacitance of value depends on what factor. One is the dielectric thickness, means gap between the top electrode and bottom electrode.Dielectric constant of the dielectric medium and what is the third, the overlapping area. These are the three parameters based on which the capacitance value will change.Now in this kind of structure if there is vertical motion of this particular upper cantilever beam, if it vibrates top and bottom, then what will happen? Then the gap between the top electrode and bottom electrode will change.

So automatically the delta C will change. There is another configuration in this side. Number one, configuration you see here now here again the pickup plate is this plate bottom plate is pickup plate. Top one is cantilever beam. If the cantilever beam is fixed, now the pickup plate if it a moves in lateral direction,so how much is the overlap area if moves in this direction for example here and hereand automatically the overlap area between top and bottom electrode will change and because of the change of overlap area, capacitance will change. Here, the dielectric constant is not going to change and gap between the top and bottom electrode is not going change. But the area overlap area A is going to change. So depending on your requirement both the techniques is useful. You can use either the technique one or you can use technique two. In one case, one of the top electrodes is going to change. Another case the bottom is moved in lateral direction so that the overlap area may change. So this is an example of simple cantilever beam. How it can be used for capacity pickup?

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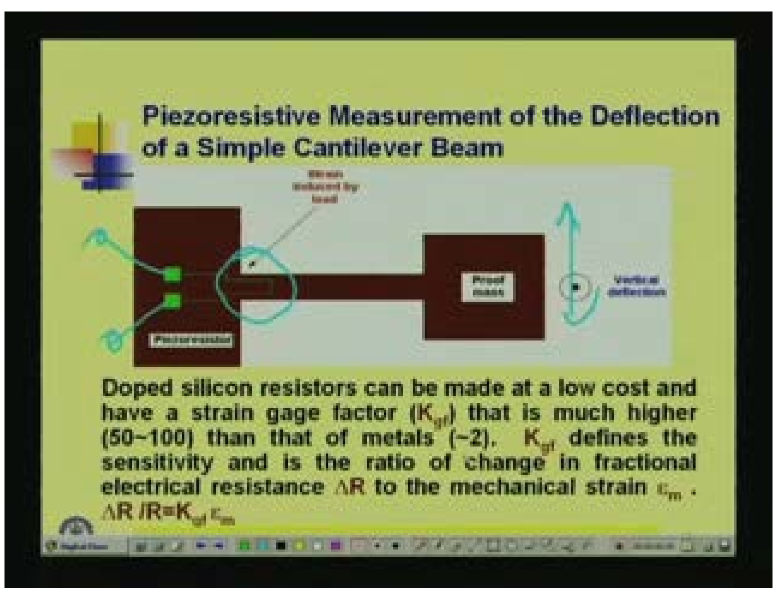

Next is the piezoresistive measurement of the deflection of a simple cantilever beam.So is a piezoresistive pickup is explained here. You can see here a structure which is having a prove mask and a bridge kind of thing. In earlier view graph I showed some bridge kind of thing. The similar here is a bridge; this bridge has got two supports; one is this and another is a one right hand side, another left hand side, two support beams are there and in between that,there is a bridge which is a thin kind of cantilever. But cantilever the open end there is proof mask attached to the cantilever and now depending on the vertical moment or motion or pressure on the proof mask the bend the flexure will bend. It will deform and if you can make a piezoresistor in this particular location which is highly sensitive location and here this particular region is highly sensitive region. If you make a piezoresistor in this region and then automatically the moment of the proof mask top and if vertically you move top and bottom then here, there will be a bend and there maximum stress region the piezoresistance will change and here you can just measure the resistance values.

Or if you want to convert the resistance value into a voltage change. So accordingly you can use certain circuit like Wheatstone bridge, similar kind of things so you can get the resistance change convert into voltage change. Now what is done here? Doped silicon resistance are fabricated which is very common in normal integrated circuit technology and this technology is well established. So the cost will be less and doped silicon will have a strain gage factor which is known as K_{gf} and this much higher than that of metal. Gage factor K_{gf}defines the sensitivity and is the ratio of the change in fractional electrical resistance change delta to the mechanical strain in epsilon m. That is the K_{gf}which is known as a gage factor and strain gage factor of silicon is in the range of 50 to 100. Whereas the strain gage factor $K_{gf}$of metal is of the order2. So metal strain gage which are being used quite a long time in civil engineering people. Where deformation of beam, the moment of the bridge so heavy structure deformation. Those people use many strain gage sensors and those are basically thin film metals. But we found that gage factor on the metal strain gage is nearly 2.

On the other hand silicon strain gage has gage factor nearly 50 to 100 is enormously high. But those resistances which is the doped silicon has to be made on very thin membrane and those thin membrane or thin flexure has to be fixed on the heavy structure whose strain we want to measure. So that was not available in earlier days. That is why they used to make thin film metal strain gage. But due to the advent of the micromachining technology, now this doped resistance its gage factor is very high. Doped silicon resistor if gage factor is very high, that is being used in strain gage for strain measurement of the heavy structure when it is deformed. So that is the $K_{gf}$and utilizing that strain gage of factor we can make sensors which may have lot of application in mechanical and civil engineering devices.

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Now silicon; single crystal silicon is a very good piezoresistive material and it is highly suited for the conversion of mechanical deformation to an electrical signal and is used as the basic material for piezoresistive sensors, for mechanical signals such as pressure, flow, force, acceleration. Why silicon is an advantageous material? I told you in earlier lecture. Also I explain in detail. But here some of the salient points again I will highlight before going into detail of the mechanical sensor. Silicon piezoresistive sensors show better performance compared with the classical metal strain gage just now I explained why it is better.

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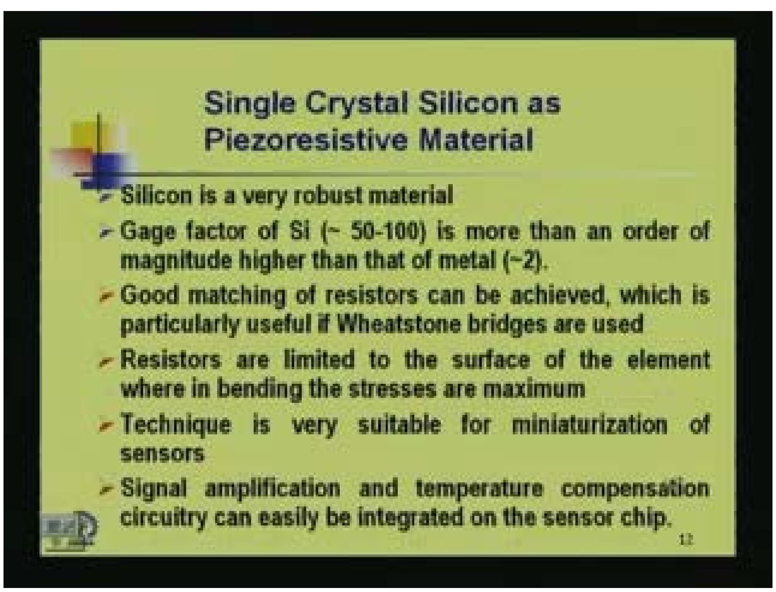

Now single crystal silicon as piezoresistive material and its advantages is many fold. Namely silicon is a very robust material gage factor. Just now I told is enormously high compared to the metal strain gage. Other parameters which tempted the people to use the signal crystal piezoresistive material for sensor of mechanical sensor application are good matching of resistors can be achieved which is particularly useful if Wheatstone bridges are used. Because Wheatstone bridge has to be balanced. So for that you need good matching of the resistors. Resistors are limited to the surface of the element where in bending the stresses are maximum. That is very important parameter, important point. What is that? This doped silicon resistance, why you donot make in the interior bulk of the silicon.

It is made at the surface because, what is the junction depth of those doped piezoresistance is nearly 2 micron or 2.5 micron. That is near the surfacewhere total thickness of the vapor is 500 micrometer and you are making the resistance within 2 to 2.5 micrometer. That means this is in the surfaceand this kind of the high sensitive stress regions are where at the surface. So that is why since, you can easily make the element at the surface which is bending. So then you can pick up the maximum signal out of the deformation. Techniques is very suitable for miniaturization of sensor I should not repeat it. Signal amplification and temperature compensation circuitry can easily be integrated on the sensor chip. That I highlighted many times earlier also.

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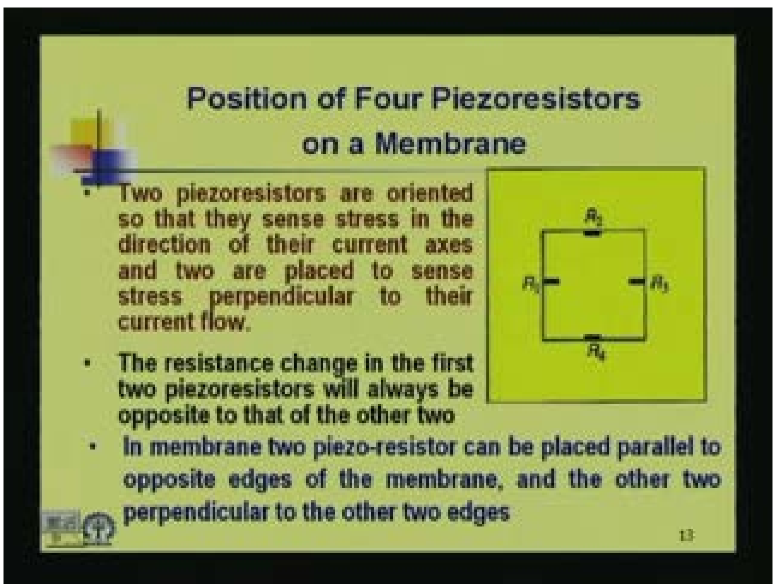

Now here I will show you the diagram or which the 4 piezoresistors are fabricated and where at the actual location. If you want to use a Wheatstone bridge for sensing, the resistance changes in terms of voltage. So you have to make a bridge and that Wheatstone bridge you know there are 4 resistances. Then those 4 resistances we will give you the non-condition of the bridge if there is no force applied on the sensor. That means when sensor is not sensing the measurement, normally the bridge should be balanced. So that means the 4 resistances should be exactly matched. But by small change of the mechanical energy, so you have to have a large amount ofthe output, Wheatstone bridge output. In order to achieve that, location of the piezoresistance are very important point, important aspect where we will place the resistances and here in this diagram I will mention how this resistances are placed. 2piezoresistors are oriented so that they can sense stresses in the direction of their current axes and 2 are placed to sense stress perpendicular to the current flow. One will be direction of the current access; other two will be the perpendicular to the direction of the current flow.

That is why you can see here, all the resistances are not made in the similar fashion here and these two resistances are same similar fashion. It is oriented by these two are not similar fashion Isn't it? And you can see here the $R_1$and $R_3$are parallel to the opposite edges. But $R_2$and $R_4$are perpendicular to the opposite edges. So that if there is a deformation on the beam, so that change of since one is parallel, one is a perpendicular, though change will be more. So that your pickup signal will be more. The resistance change in the first two piezoresistors will always be opposite to that of the other two, because we have placed in opposite fashion. Two are parallel to these; another two is perpendicular to opposite edges so the resistance changes will be opposite. In membrane two piezo-resistors can be placed parallel to the opposite edges of the membrane and the other two perpendiculars to the other two edges just now as I mention.

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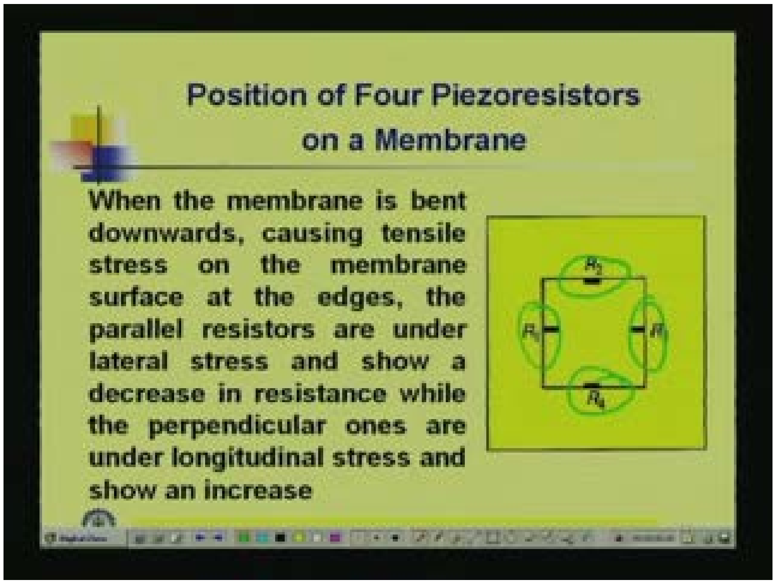

Now what will happen if the membrane is bends downwards?If the membrane which is shown here is bent downwards, that means if you apply pressure on it, it will cause tensile stress on the membrane surface at the edges. At the edges means this is the edge, this is the edge, this is the edge and this is the edge. On the four edgesit will produce tensile stress, the parallel resistors, resistors which are parallel to the opposite edges. This the parallel $R_1$and R_2opposite edges the parallel resistors are under lateral stress and show a decrease in resistance. Whereas the perpendicular ones are under longitudinal stress and show an increase. So if you place resistance in this fashion, so two resistance which are parallel, they will undergo the lateral stress and due to which the resistance will decrease and two resistance will experience perpendicular stress longitudinal stress and because of which resistance will decrease. So two will increase, another two will decrease. So from the original value totally difference is more and because of that effectwhat will happen? You will get a large amount of the signal pickup. So you will now understand the position of the piezoresistors on a membrane or crucial phenomenon crucial matter, crucial judgment to get much more sensitivity.

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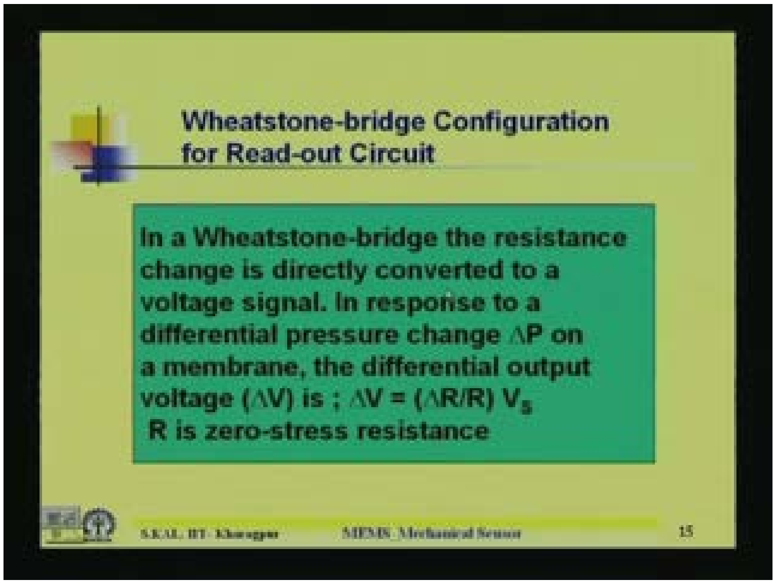

Now in Wheatstone's bridge, the resistance change is directly converted to a voltage signal. In response to a differential pressure, change delta P on a membrane, the differential output voltage delta V is delta V equal to delta R by R into V_S where R is a zero stress resistance. This is output voltage after the change of resistance because of the stress.

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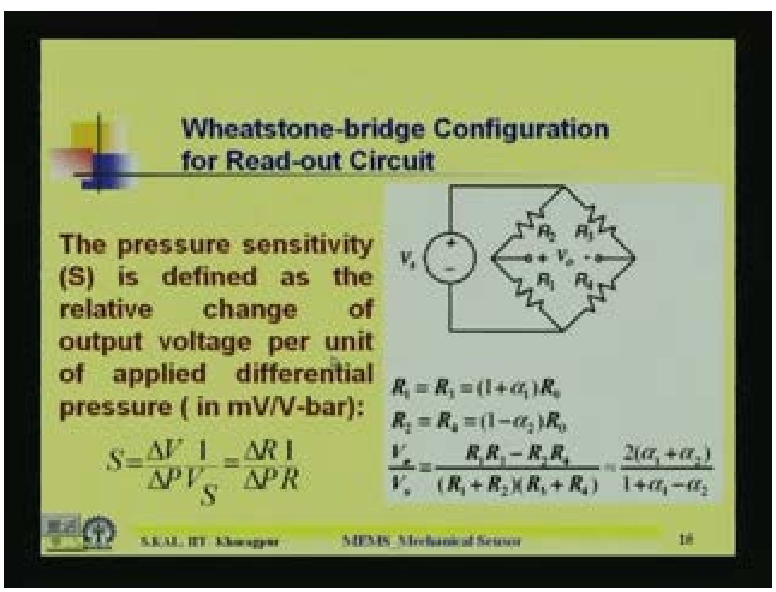

Now here is the bridge and how to connect? This is the output voltage, here you are applying the input voltage and the R_1equal to R_3opposite are equal and $R_2$and $R_4$are this. As I told one will expense the lateral stress, another will expense the longitudinal stress. So as a result of which one will be 1 plus alpha R_0, another is 1 minus alpha 2 into $R_0$and $V_0$by V_S in terms of resistance is express by this relation R_1, R_3minus R_2,R_4, divided by R_1plus R_2 into R_3 plus R_4. Which if you replace the resistances in terms of all the alpha 1 and alpha 2 the piezoresistive coefficient under lateral stress and longitudinal stress. One is the lateral stress other is for longitudinal stress alpha 1 and alpha 2. So according the resistance value will change and now if you put those, replace those resistances in terms of alpha 1, alpha 2 then $V_0$by V_S will give you this relation. Now alpha 1 alpha 2 change is the important parameter which you have to get from other sources. There are tables available where you can get the piezoresistance coefficient change with respect to this stress developed. Now the pressure sensitivity is defined as the relative change of the output voltage per unit of applied differential pressureand is expressed in milivolt by volt bar and it is mathematically, it is expressed as delta V by delta P 1 by V_S is equal to delta R by delta P into 1 by R. That is the pressure sensitivity.

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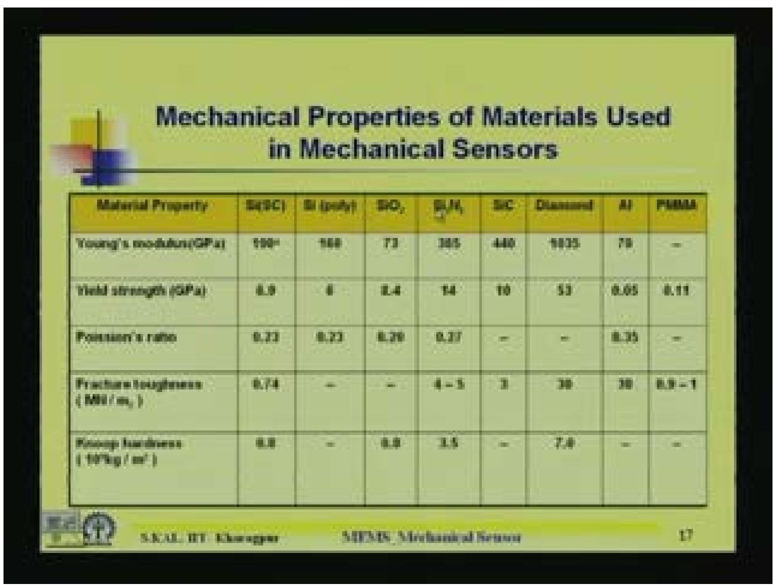

Now here is a tablewhich shows mechanical properties of the materials used in different microsensors. What are those properties? Young's modulus, Yield strength, Poisson's ratio, Fracture toughness, Knoop hardness. These are the mechanical properties which are the parameters people look for selecting the proper material, for sensing the mechanical energyand here materials normally used are, you see is single crystal silicon, poly crystal silicon, silicon dioxide, silicon nitrate, silicon carbide, diamond, aluminum and PMMA polymethyl methacrylate which is theorganic polymer. So polymers are there, ceramic materials are there, silicon carbide, silicon dioxide, silicon nitrate to dielectric material semiconductor materials are there, diamond is also there. Now if you compare, then in many respect we will find the single crystal silicon has very good mechanical properties which I mention earlier also.

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Now, sometime I will concentrate now on micromachine pressure sensor. So micromachine pressure sensor is a mechanical sensors which occupy the major chunk of the mechanical microsensor, markerthe pressure sensor and what are the various ranges of pressure sensor use for various application it is shown in this table.

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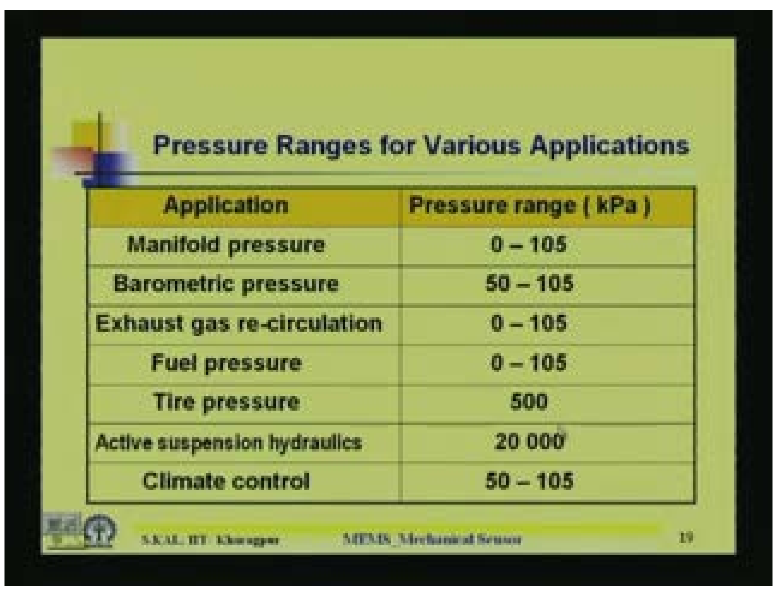

Application	Pressure range (kPa)
Manifold pressure	0 – 105
Barometric pressure	50 – 105
Exhaust gas re-circulation	0 – 105
Fuel pressure	0 – 105
Tire pressure	500
Active suspension hydraulics	20 000
Climate control	50 – 105

0 to 105 kilopascal, many fold pressure. That means there is miscellaneous application for many equipments aremany applications. Barometric pressure normally use 50 to 105 kilopascal. Exhaust gas re-circulation there people use 0 to 105 kilopascal again. Fuel pressure is 0 to 105 kilopascal, tire pressure of the automobile 500 kilopascal. This is the pressure range, so

accordingly your design will change. Which range you are interested to measure the pressure, depending on that, your microstructure design you have to make. Active suspension hydraulics that is 20000 kilopascal. Climate control 50 to 105 kilopascal. Climate control means basically the barometric pressure. So these are different pressure ranges for different applications.

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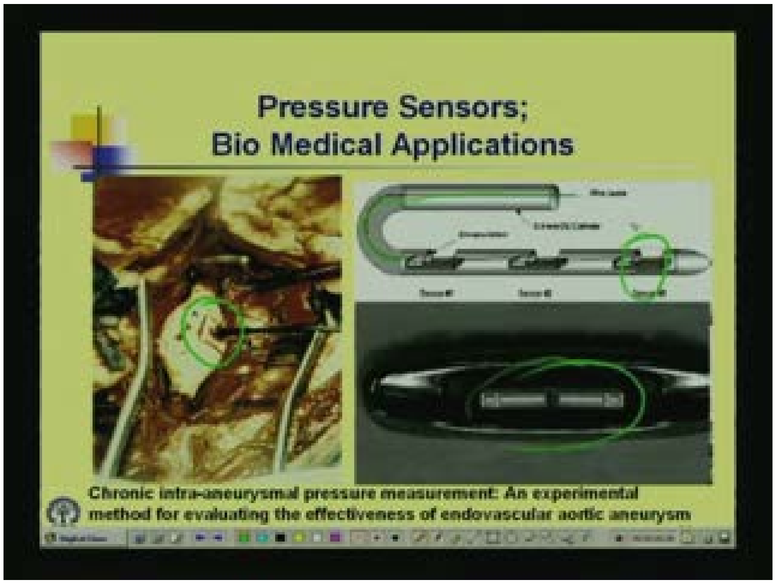

Now here are again some applications related to biomedical pressure sensor you shown and in the left side you can see the diagram. Here is basically the muscle contractionand then it will create a pressure if you pump inside your body. So you see here a pressure, you can see here this particular portion a pressure sensor is fixed on that muscle. So that during the expansion and contraction of that muscle in how much pressure is created on the muscle that you can monitor and it is basically connected to a catheter. So it is a biological sensor, two things we have to remember always. One the sense in material are the catheter through which you are guiding the pressure sensor must be biocompatible. So you will not harm the biological fluids. You should not react with the biological fluid inside the body. That is known as the biocompatibility. So here is a catheter arrangement is shown in the diagram.

In this side you can see this is the wire which is basically passing through it and then this catheter outer diameter you can see here is a 0.5 millimeter. So this is the catheter diameters which can easily a pass through a body to vein or some something elseand sensor is placed here. So this is fixed onto your muscle or biological body whose contraction, expansion you want to measure and the blow of the view is shown here in this picture down and you can see here the some faint figure is there. The kind of the bridge or some kind of membrane kind of thing has been formed here on the material which is micromachine and fixed in the catheter. It is small portion is blow of version is shown here. So this is one kind of pressure sensor which is different from the barometer application or tire pressure application. Now another kind of the pressure sensor we will see here in the next view graph.

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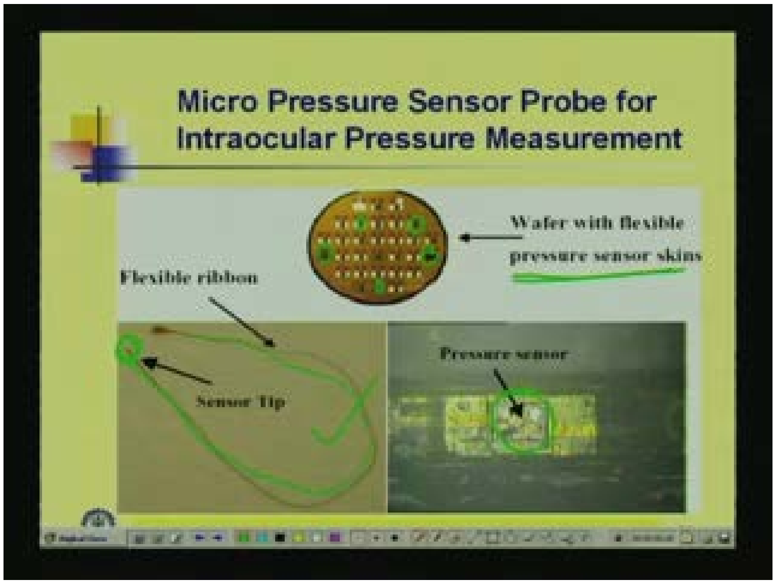

That is here for intraocular pressure measurement that is also an important application area. That means in your eyethere are fluids flowing inside the eye and the flow of the fluid in the eye, how much pressure is applied on the retina that is very important for perfect view. That means if the pressure changes your vision capacity is also going to change. So the eye specialist many times they measure the pressure of the fluid in your eye. So in order to measure you need a pressure sensor for intraocular pressure measurement and there you have to have a media which must in flexible which is known as a pressure sensor skin. So these small portion you can see here. These are the sensor you can see, these sensor, sensor, sensor, sensor, different kind of sensorand these are actually pasted on a biocompatible skin which is known as pressure sensor skinand the whole vapor is flexible. So that perfectly you can place it on the retina. Retina is not plain surface; it can if the module or the sensor you want to fix must have flexibility. So now if you fix that and now if you want, this is one kind of pressure sensor on surface, you can fix.

But if you want to have, if you want to change the pressure inside your eyeball or inside the eye some interior portion, then you have to drive the sensor through a ribbon and here is shown in this kind of sensor. This is a flexible ribbon which is going inside the interior location of eye.So here is the tip and in this tip the sensor is mounted and this tip is the enlarge version of the tip is shown here. Here is the pressure sensor. You can see the enlarged version, this is fixed on the tip and through the ribbon you can push it into the interior location to measure the intraocular pressure. So this is another kind of application which is totally different from automobile pressure application or barometric pressure application. So obviously most crucial as I mentioned there has to very small insize and there has to be materialized to a biocompatible. At the same time there should not be any hysteresis. Those properties has to be maintained when you are designing this kind of sensor or you are going to fabricate this kind of sensor.

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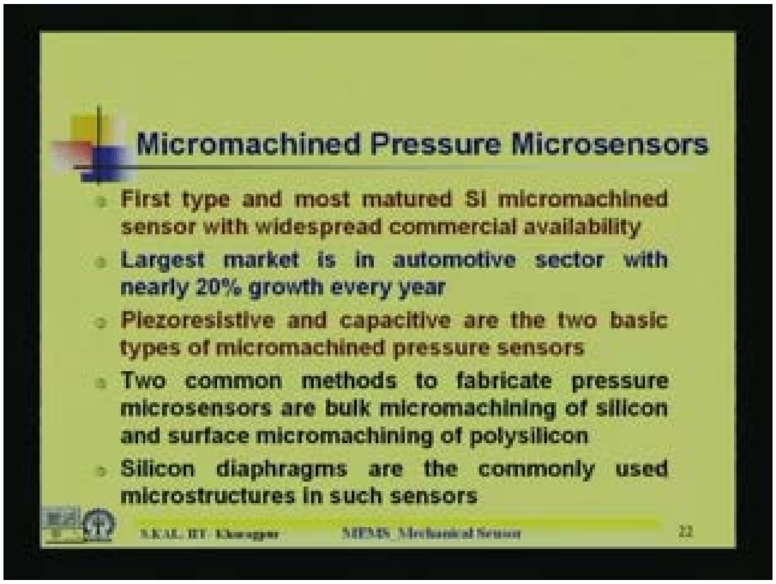

So the micromachined pressure sensor. If we continue our discussion on that, it is one of the sensor which has evolved at the beginning of the microsystem or MEMS technology. It is a first type and most matured silicon micromachined sensor with the widespread commercial availability. I think out of the MEMS sensor available in the market. Commercial availability pressure sensor is the requirement or availability is the highest is a most matured. Largest market is in automotive sector with nearly 20 percent growth. Every year of the only pressure sensor, 20 percent growth every year. Piezoresistive and capacitive are the two basic types of micromachine pressure sensor people are now concentrating and also marketing. Two common methods to fabricate pressure sensors are bulk micromachining of silicon and surface micromachining of polysilicon. When they go for further miniaturization and having some circuit adjacent to the sensor, then they go for surface micromachining using polysilicon.

But if you do not need the circuit only the pressure sensing element, then for example in car tyre pressure you want to measure only pressure. There is no signal conditioning circuit in that locality. Because car mechanical vibration and rotation is tremendous. With that mechanical vibration and rotation if you integrate certain circuit surely will not be very good. So in those cases, these circuits are basically, these are the signal conditioning circuits arein infinite region. IR sensors are used and the remote using the remote control with the IR energy, the electronic is kept not in that harsh environment but in other location. It is kept there and it is an accessing remote key. But there you can use the bulk micromachining of silicon because you need much more stability. You need the maximum sensitivity. Silicon diaphragms are the commonly used microstructure in such sensor. In most cases either silicon diaphragm or the cantilever at the tip or at the bend of the cantilever. There you can make the I have shown in the diagram you can make the sensor.

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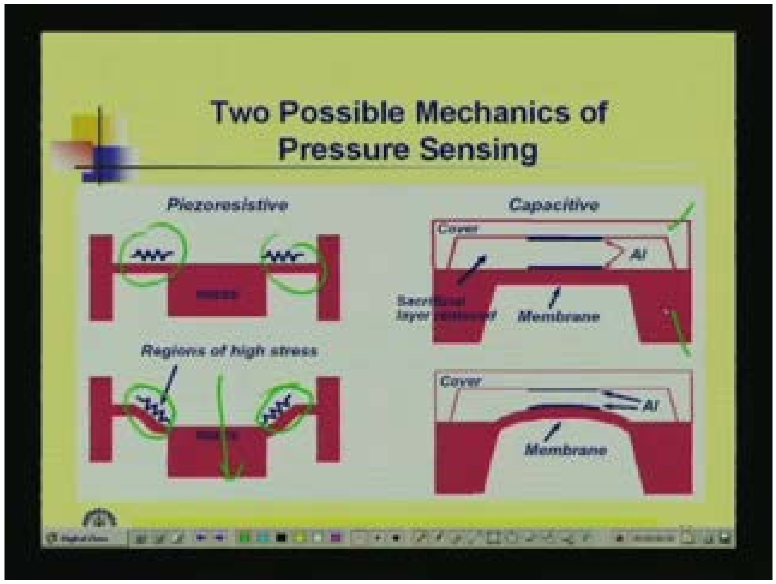

Now these are two kinds two possible mechanics of the pressure sensing normally made here.One is the piezoresistive, another is the capacitive. You can see here what I explained here the some cross section view we have shown. So that you can understand easily. So these are mask here is one resistance, this is one resistance and this is another resistance. So regions of high stress, under the stress if the mask is bend downward, so automatically the resistance which is placed here and here. That will be in the high stress region here and so automatically the region high stress and this will changeand here is another structure which is a capacitive structure. There you can see that here basically two structure; this is one, this is the second. So first structure you can make the membrane and there you can have an electrode. After having electrode you membrane. Then another the layer this is one separate silicon wafer you can design the cover and the cover is also etched and then there also you can attach the aluminum pad. So that this is the parallel plate capacitance in the gap you can adjust, you can micromachine this top layer to make the gapand here you see you are not going to use the material properties to sense.

That means you may not use silicon here. It is basically the external capacitance you are making parallel plate capacitance. S there this is not necessary that always we use the silicon, you may use glass, also glass micromachining and but thing is thatat the end of the fabrication of these two electrode plates you have to bounding. That is the cover and the bottom layer has to be bounding. So that bounding is the either eutectic bounding or you can have the epoxy bounding or the thermal compression bounding, different kind bounding is available bounding. NOD bounding technique that I will discuss detail in some other lecture. So there at the any of the fix of these two. Similarly here, now in this kind of capacitive sensor if there is a say pressure in this side membrane will bend in this fashion. So automatically here the gap you see, what are the gap here, that gap is changed here in this portion.So accordingly the capacitance will change. So these are the two mechanics of pressure sensing arrangement.

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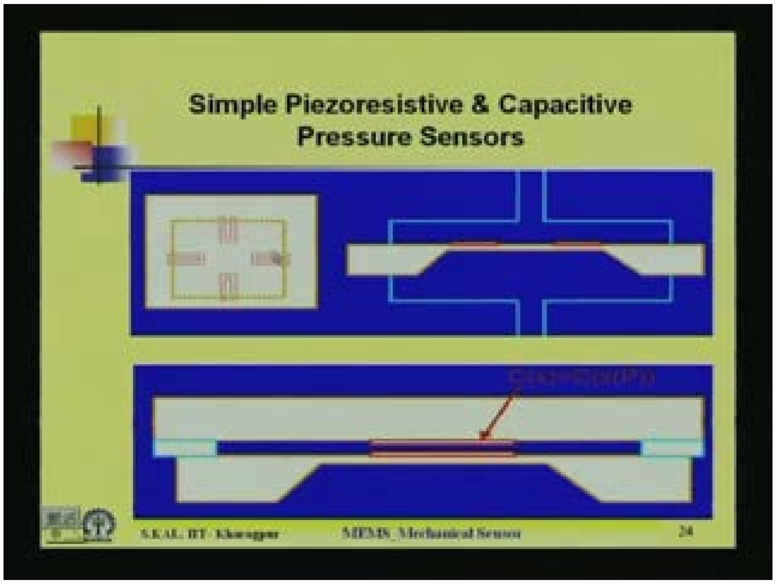

So now here is again the simple piezoresistive and capacity pressure sensors some the another diagrams are shown here similar kind of diagram. So the location and the encapsulation is shown here. These are the resistance positions here and here is capacitance, the parallel plate capacitance which is the function of the gap as well as the area.

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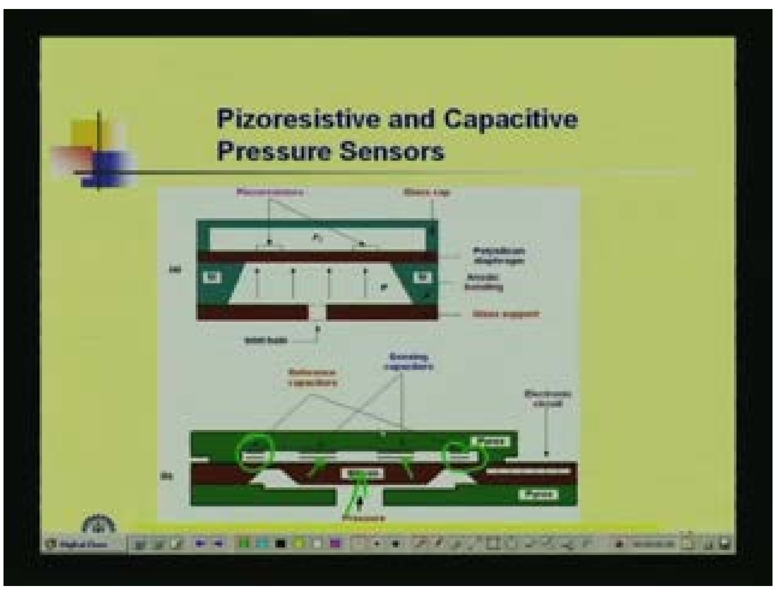

Now here are the three structures.Basically here in this particular diagram you can see this is capacitive and in this capacitive in the bottom one you can see there are three pieces of the microstructure. Top is a pyrex glass, bottom is also pyrex glass and the middle you have used silicon. So three layer and here instead of making of one capacitance so what is done here, you can see there are four capacitor and out of the four capacitance, two capacitors are made on the rim portionand those capacitors are not going to change due to the pressure on the proof mask. So this location and you can see this one and this one. These two are basically on the, it is not shown clearly. This is on the rim side. So there, basically known as difference capacitance. Now with respect to difference capacitance, but these are two sensing capacitance this one and this one. The pressure if we apply like that in a cavity, the proof mask is going to go up. So accordingly this will change, but this will not change. So you can have the differential capacitor that is very important. Why the differential capacitance is important? Because if you go for only single capacitance, the problem is the parasitics.

Lot of parasitics capacitance will be there in the complete structure. Those parasitics are coming, if there are some metal, there are some layer separated by dielectric median on the silicon wafer or even you are using bounding pad they will contribute some capacitance. Even any ground plane is there with respect to the semiconductor there will be some parasitic capacitance and in the wiring too. Because you are using the connecting wire when this is moving in a package. So two wires are separated by air is dielectric. So that will contribute certain capacitance. Those are parasitic on capacitance and those effect has to be neglected. So there what has been done? So that is why they go for differential capacitance measurement. That means whatever the parasitic, let it be there. But if two are fixed, similar capacitance two are changed. Because of the pressure change and proof mask will change, those two will change. So if we go for this kind of technique, then perhaps we can avoid most of the parasitic effect in our measurement. The major difficulty is in this kind of the sensor is the parasitic capacitance effect.

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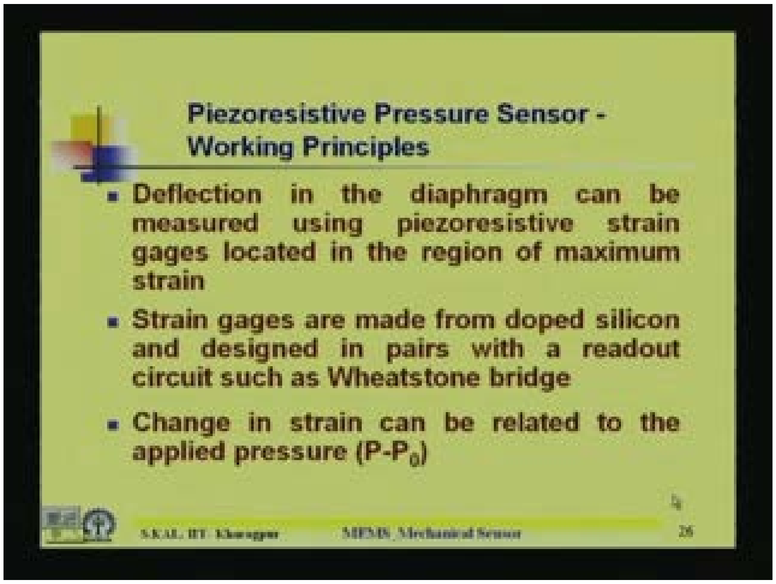

Now working principle of this kind of pressure sensor is the deflection in the diaphragm can be measured using the piezoresistive strain gages located in the region of the maximum strength.Strain gages are made from doped silicon and design in pairs with a readout circuit such as Wheatstone bridge. Change in strain can be related to the applied pressure. So these are the basic, is nothing new. I explained earlier also.

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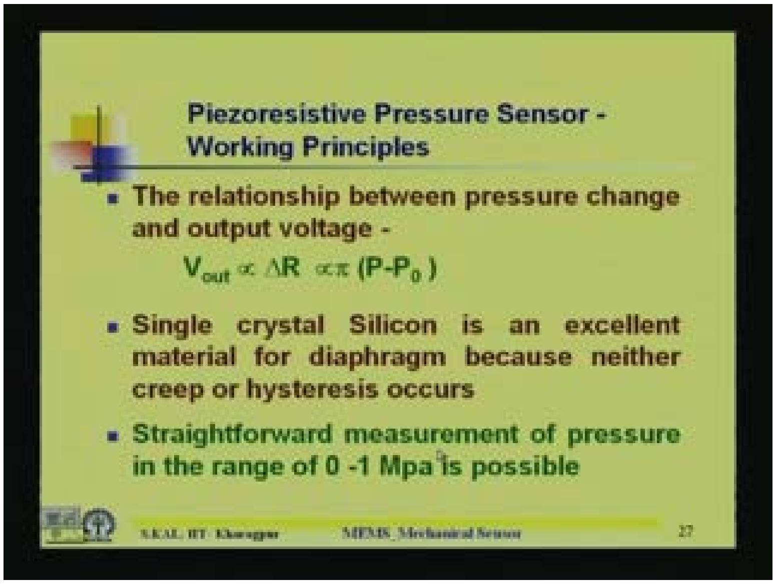

The working principle is again the relationship between the pressure change and output voltage is like that. V output is proportion to delta which is proportion to pi into P minus P_0. This pi is the piezoresistive coefficient P and P_0. $P_0$is the constant pressure in the waveform in the chamber and P is the external pressure. Single crystal silicon is an excellent material for diaphragm because neither creep or hysteresis occur. Silicon does not have any hysteresis effect. It neither have creep effect, so this is an ideal material for the diaphragm. Straightforward measurement of pressure in the range of 0 to 1 megapascal. It is possible with help of the piezoresistive pressure sensor.

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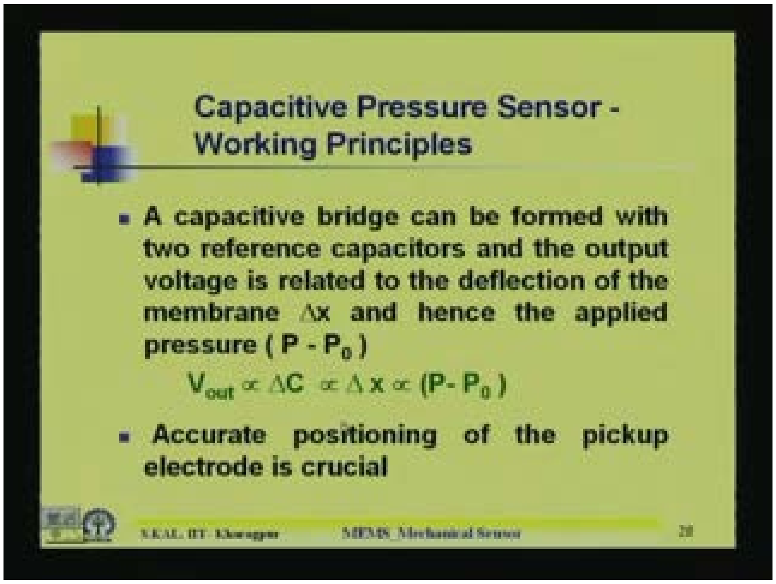

Now in case of capacitive pressure pickup, what is the basic principle? A capacitive bridge can be formed with two reference capacitors and the two and the output voltage is related to the defection of the membrane delta X. This is the deflection and the applied pressure P minus P_0, the V_{out} will proportion to delta Cand which is again proportion to delta X. Delta X means you are going to change the deflection as a result of which the gap between the two parallel plates we will going to change and which will change which is proportion to P minus P_0. So there are basically the P minus P_0change is going to change first delta X deflection change. Delta X is changing the delta C and delta C changing V_{out}. So that means it is a not direct. There are certain steps through which you getting the voltage change. Accurate positioning of the pickup electrode is a crucial that we have seen.

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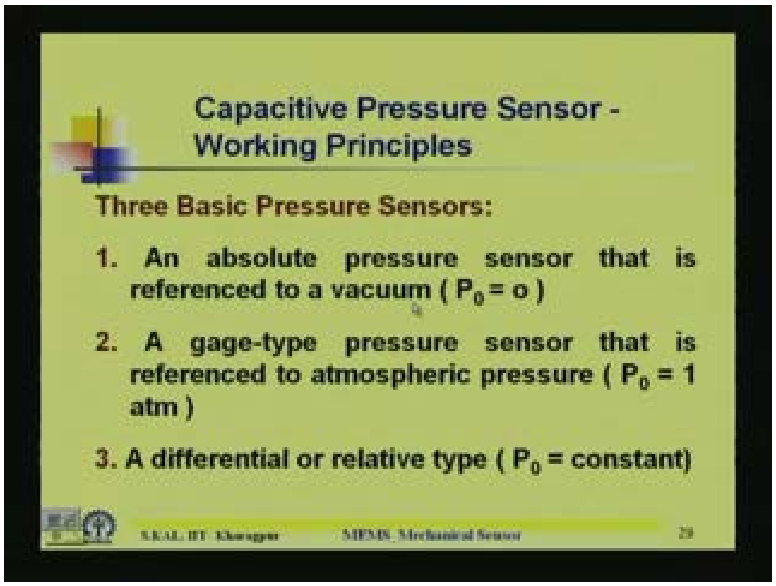

Now the basic pressure sensor is an absolute sensor that is referred with respect to vacuum. There are three kinds of pressure sensors. One is the absolute pressure sensor where the P_0equal to 0. That means inside the cavity, cavity has to be kept in vacuum. So pressure measure with respect to the vacuum that is the absolute pressure. Second one is gage type pressure sensor that is reference to atmospheric pressureand atmospheric pressure is P_0equal to 1 atmosphere. That means inside the cavity where the capacitance is the parallel plate capacitance are fabricated there, the atmospheric pressure is to be maintained. That is known as a gage type pressure sensor another is a known as a differential or relative type. There P_0inside the cavity is constant but that value may change, may not be atmospheric pressure. But many other pressure, there you can have a differential or relative pressure. Now these are the working principles. In the next class I will just discuss on the compression and total design and analysis of a particular typical piezoresistive pressure sensor. Compression as well as the fabrication and design. How go for the designing, how do you analyze this part, I will discuss in the next class. Thank you very much.