A Brief Introduction to Micro Sensors
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Lecture - 17
Pressure Sensor - I

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Hello, so, today we will start our next and last module, that is module 4 on case studies. Now, here we will actually discuss on one or two particular sensor of MEMS field, ok, but before going to that lets revisit once that, what are the different things we learnt. In the first module we learnt about in general, what is the MEMS sensor, how does it work and then why we need to go down to like micro or nano scale and what does it change actually in that once we are going from macro to micro or nano scale?

And, then we studied different mechanical structures and how like what is the relation between the force and deflection. If we apply some force then how the deflection will be or how the deflection will be related to the force and then also we learnt that, how in the second module we learnt that how we can actually measure the deflection using capacity method or electrostatic technique and then in the third module we discussed about different sensors fabrication; like what are the different fabrication technique, how we remove a material like etching, how we deposit a material like evaporation and different kind of coating techniques and now, we are going to discuss on a particular sensor. And, first our first case study will be on pressure sensor.

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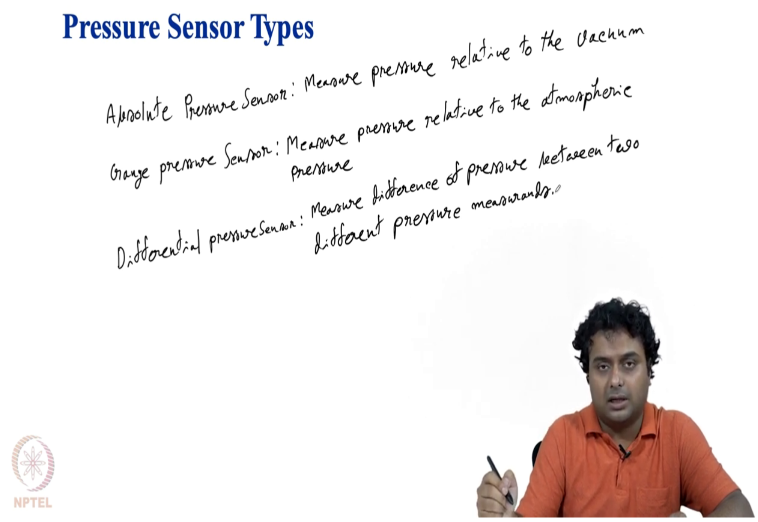

So, let us discuss about pressure sensor. So, what are different types of pressure sensors? For pressure sensors we know that what it does, it actually, measures the pressure; pressure of the gas or pressure of the liquid or in a chamber with whatever is our requirement.

Now, what are different kinds of pressure sensors? The first type is absolute pressure sensor. And in that we measure pressure relative to vacuum. So, in case of absolute pressure sensor we measure the pressure relative to the vacuum. If we consider vacuum to be 0 pressure then whatever pressure we measure with respect to 0 and that is our absolute pressure sensor. Like atmospheric pressure environment is example, of absolute pressure sensor.

Next is gauge pressure sensor; here we measure pressure relative to the atmosphere, atmospheric pressure. Then we have like differential pressure sensor, before we go to differential pressure sensor; what is the application of this pressure? Like; blood pressure right. So, blood pressure while we measure a patient blood pressure that is relative to the ambient or the atmosphere, right. So, that is example of gauge pressure sensor.

Now, differential pressure sensor; here what we do? We actually measure pressure or measure actually, difference of pressure between two different pressure measurands. So, let us say you have a application such that that you have two chamber and you have to measure the pressure difference between them. So, in that case we can use this kind of differential pressure sensor and example is; like high pressure oxidation chambers or things like that.

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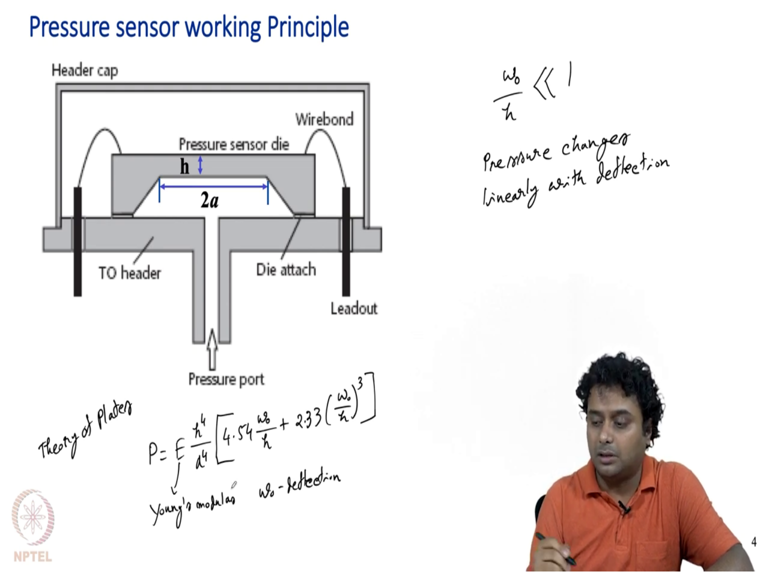

Now, pressure sensor working principal; so, this is the general diagram of a pressure sensor where we have a membrane; like this as you can see here we have a membrane and then here is the pressure port pressure port, right. And, the top side is can be vacuum or can be atmosphere at like atmospheric pressure or some other gas pressure also depending on what kind of pressure gauge it is; like whether it is absolute pressure sensor or differential resistance or gauge pressure sensor accordingly this top side will be decided.

So, let us assume that this is packaged under vacuum and this side the top side is vacuum ok. Now, this is the pressure port of which actually, we are measuring the pressure. So, this is connected to some chamber this is connected to some chamber of which pressure we are measuring. Now, as the pressure of the gas pressure come; then what it will happen? It will have like ballooning effect and this will this membrane will be deflected, this membrane will deflect like that little bit, ok. And, we will measure this deflection of the membrane by some technique and can calculate the pressure.

Now, like for this case if we have the membrane of size 2a and let us say the thickness of the membrane is h, then from the theory of plates we can write that; P equal to E into h to the power 4 by a to the power 4 into 4.54 w 0 by h, where w 0 is the deflection of the membrane plus 2.33 into w 0 by h whole cube. So, here this is the expression and this comes from theory of plates.

Which is not part of this course and this is the basics mechanical course actually, from that we can derive this expression. Now, what is this E? This E is Young's modulus, h is the thickness of the membrane, a is the; like 2a is the total length of the membrane, right and so, a is the center like this distance from the center, like from the center to the periphery it is a, w 0 is the deflection of the membrane, right. So, w 0 is deflection.

And, so, all of these terms like h is a geometry property, right whatever dimension we make the membrane accordingly we know h, we know a and we know E this is material property and we if we measures, if we can measure w 0 then we can get P very easily like what is the using this expression, we can calculate the pressure. Now, one thing we need to understand is this P is the difference between the top side and the bottom side and as the as the pressure changes, accordingly we will have the deflection.

Now, deflection this deflection and pressure is the non-linear function of deflection for any general deflection right, but if the w 0 is pretty small if w 0 by h very small then one then what we can write is; pressure changes linearly with deflection, because we can then neglect this w 0 by h whole cube term and accordingly we can just get P varies with w 0 or this is linear and most of the sensors while, we apply for real application we actually need this kind of linear relation, because it makes our analysis and use easier.

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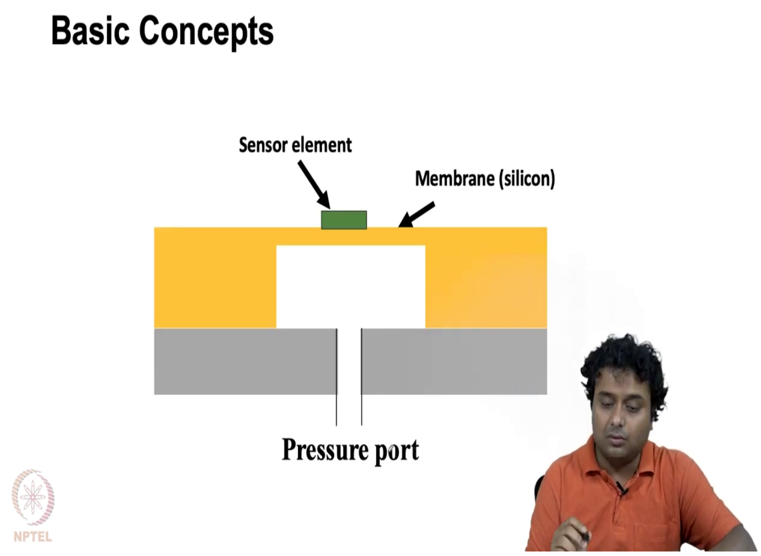

Now, what is the basic concept of this pressure sensor as we have shown that, there is a pressure port through which the which is connected to the membrane and as we apply some pressure the membrane deflects, right. Because it has in this region the pressure is different from compared to this region. So, the membrane will deflect. Now, we can put some sensing element on top or some sensing technique to measure this deflection, right and accordingly we can measure the pressure.

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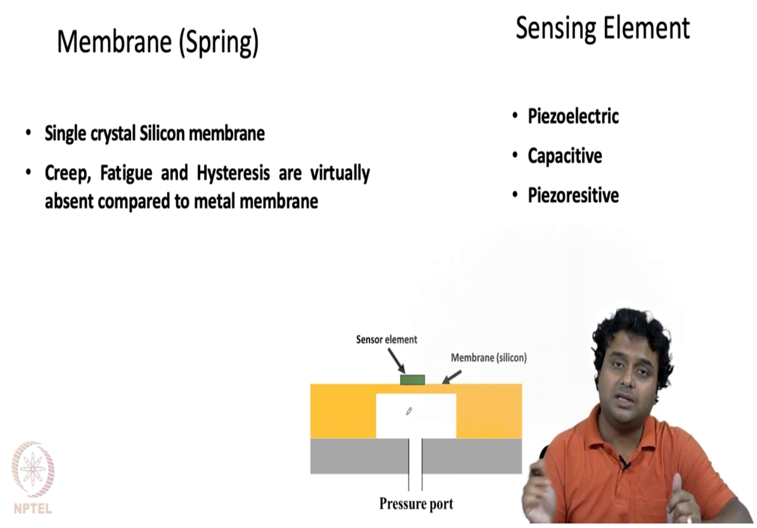

Now, what are like what can be choosed as membrane? First is the our first option or the most popular option is single crystal silicon membrane, because the creep fatigue or hysteresis effect are virtually absent in that case. So, whatever let us say we apply some pressure and after we release that if we remove that pressure then the membrane comes back to its original position, without any creep or fatigue and for silicon; actually the Young's modulus and its deflection properties are very well known and standard.

So, it is usually silicon or Si O 2 membranes are used for this kind of pressure sensors. Now, for sensing element also we have different options. One option is piezoelectric sensors. So, piezoelectric sensors mean that while we are coating this sensor this will be a piezoelectric material. Now, what is the property of piezoelectric material? It is if we apply some kind of stress or strain on the piezoelectric material then it generates some voltage, ok.

So, let us say let us say this is a cantilever or membrane and on top of that we have some piezoelectric material, then as we deflect or apply some stress then this piezoelectric material is also under that stress and this will generate an electric voltage at that at that element. So, if we can measure that electric voltage and then accordingly, we can measure how much is the deflection and how much is the pressure.

So, this is one case another case is capacitive; like as you can see that in the like one of the previous module, you have seen that capacitive how does capacitive measurement work for electrostatic case, right. So, as the membrane deflects the distance between the top plate and the bottom is different, right. Because it is it has now, become like a bulge and this minute change in the deflection can be captured by its capacitor, because capacitance for parallel plate arrangement is C equal to epsilon a by d. Where d is the distance between the two plates and so, we can measure the distance between two plates by measuring their capacitance also.

Another is piezoresistive so, in this case what we do? The material we put has a piezo is a piezoresistive material, right. So, piezoresistive material what is happens is as we apply the force then in the piezoresistive material, the resistance of the material actually changes and because of that if we can measure the resistance then we can measure that how much is the deflection and how much is the pressure generated.

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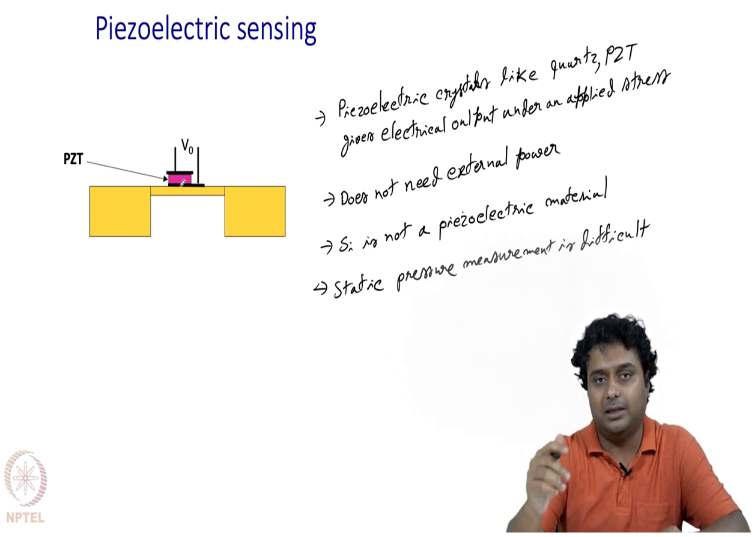

So, let us move to the first case that is piezoelectric sensing. So, as I was saying that there will be a sensing element which is piezoelectric and piezoelectric element one of the very popular example, is PZT or lead zirconium titanate. So, this material has such property that, if it is if some stress is applied on that material then some potential will be generated and that potential we can measure to measure the applied stress or to measure the pressure. So, the first point in this regard is piezo electric crystals; like quartz comma let us say PZT gives electrical output, output under an applied stress.

And, why this stress is coming? Because, the pressure is making the membrane to deflect or bent and because of that piezoelectric element this stress will be applied. So, this is one point. Now, another is this does not need any external power. So, as the voltages itself generated inside the material, we does not need to apply some voltage in this case. So, that is one of the advantage, but the limitation with this technique is silicon is not a piezoelectric material.

So, what happens is we need to we need to actually, externally glue or do something or deposit some piezoelectric material on top of that, which is not very convenient all the time with micro fabrication technique. So, this is one of the one of the disadvantage of this technique. Another is that static pressure static pressure measurement is difficult. What does it mean? Means that lets say we have some we are applying some pressure, then this piezoelectric material will be under stress so, it will generate some voltage. Actually what happens that it actually have some charge separation and that charge separation will give us the voltage.

Now, if this pressure is constant at that point then the charge also need to be static at that at the two different plates or two different electrodes, but it always does not happen, because there is always some kind of leakage happening in between the two plates, because this material is not a perfect insulator. So, the charge will leak and with time we will see that voltage again comes; like voltage decreasing the generated voltage decreases whereas, the pressure is same, right.

So, in that case it is actually little bit difficult to measure static pressure, it does not because of the charge leakage; it does not keep same output voltage, but if the lets say the membrane is vibrating so, in that case what is happening is that the charge generation is changing with time and with very high frequency. So, in if we if it is changing with high frequency, than in that small time period it does not have time to leak through the insulating material or through the piezoelectric material.

So, in that case we can measure the charge oscillation and can measure the how much frequency or amplitude is the membrane having. So, in those dynamic cases we can use this kind piezoelectric sensing.

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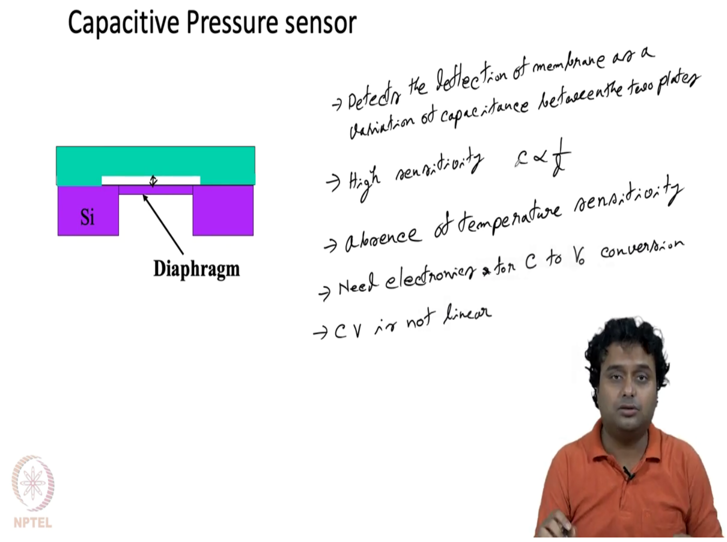

Next is capacitive pressure sensor. So, in capacity pressure sensor; we again we have the same kind of arrangement. So, we have a diaphragm like this and on the top side also we have a plate. Now, as let us say this is actually connected to the bottom side is connected to the pressure port.

So, as the material as the gas applies some pressure this membrane or diaphragm actually deflects and, accordingly the distance between this like the top plate and bottom plate this distance changes and that actually as we have discussed in module 2; that changes the capacitance or the capacitor of these two parallel plates, right. And so, the first point is that detects the deflection as a radiation of capacitance between the two plates, the important advantage of this is this is high sensitivity; very high sensitivity.

Why this is high sensitivity? Because you see c varies with one by d, right and little bit of change in d will change the C by significant amount and this d will change, because of the applied pressure. So, you can measure the change in d using capacitance and from that we can measure the pressure. Another advantage or merit of this technique is absence of absence of temperature sensitivity.

If we assume that there is no effect of temperature on the deflection; like or whatever be the pressure if we change the temperature also there will be no change in the deflection, then like pressure to deflection is not dependent on the temperature and then according to our parallel plate capacitor formula already, we know that that is also not depended on temperature. C equal to epsilon a by d which is not dependent on any of the temperature term. So, you can consider this is temperature insensitive so, at different temperatures actually we can use this technique.

Which is theoretically, but, because in practical cases sometimes this epsilon value also changes with temperature, if the temperature changes by huge amount and the epsilon can change and so, that time temperature sensitivity may come, but if we consider other cases like the piezoelectric or piezoresistive cases than it has a temperature sensor, because with temperature the piezoelectric coefficient also can change and also the piezoresistive coefficient also can change. So, this has a higher temperature sensitivity compared to the capacity pressure sensors.

But one of the you can consider it demerit if we see the in case of piezoelectric sensor, we already getting a voltage output. So, we do not need a real conversion from one kind of parameter to another, but here we need electronics circuit electronics for C to V V 0 let us say the output V zero conversion. So, we need to connect some kind of electronic circuit, which will convert the capacitance to output voltage.

And another thing is that this C to V is not linear, it is not easy to make a conversion circuit which will where the applied voltage so, ultimately whatever voltage output we will get that voltage output, may not be linear with the capacitance. So, that adds one more complexity in the sensor. So, we will start with the piezoresistive sensor in the next class.

Thank you.