Chemical Process Instrumentation
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Lecture - 29
High Vacuum Measurement (Contd.)

Welcome to lecture 29, we are talking about high vacuum measurement. So, today today we will be talking about Knudsen gage.

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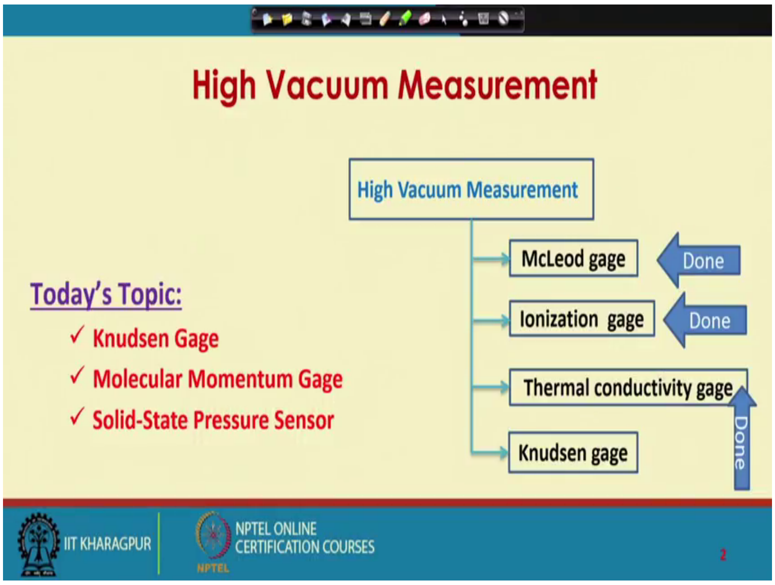

We have talked about McLeod gage, we have talked about Ionization gage, we have talked about thermal conductivity gage, we will now start our discussion today with Knudsen gage. Then we will also talk about briefly molecular momentum gage and solid state pressure sensor.

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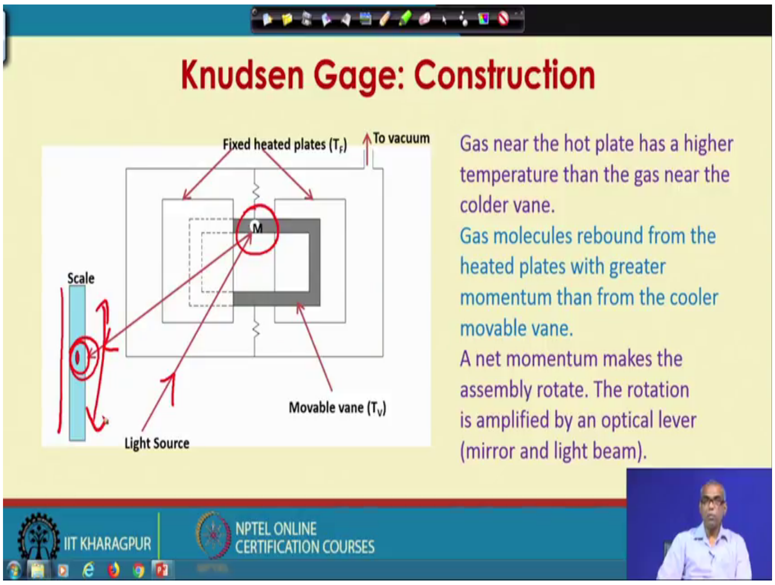

Now, what do you see is, a schematic of a Knudsen gage.

Consider a chamber to which we will admit the fluid pressure which I am going to measure. Inside the chamber I have two fixed plates, this is one plate this is another plate. So, I have two fixed plates mounted within a chamber and in between these two fixed plates, there is a spring restrained movable vane. So, you have a spring restricted movable vane in between two fixed plates. So, the movable vane can show some angular motion between two fixed plates.

Now, this two fixed plates are heated up to an exactly know temperature, and the movable vane's temperature is different from this. The temperature of the moveable vane is lower than the temperature of the two fixed plates. Now we apply vacuum; that means, you connect this chamber to the vacuum source. So, the gas is admitted to the chamber; now gas near the hot plate will have higher temperature, than the gas near the colder vane because I have heated up these two fixed plates.

So, two fixed plates temperature is higher than the temperature of the movable vane. Let us consider movable vane's temperature as same as the temperature of the gas. So, when the gas molecules rebound from the heated plates, they will rebound with greater momentum than from the cooler movable vane. Because the gas near the hot plate has higher temperature than the gas near the colder vane. So, what will happen is a net momentum will make the assembly rotate; that means, the net momentum on the movable vane will make the movable vane rotate.

Now, this rotation can be considered as a measure of the pressure or vacuum. So, how do I measure this angular rotation of movable vane? For that please note that there is a mirror attached on the movable vane. So, I send a beam of light to the mirror, and here I have put a scale and a spot of light is reflected from the mirror. So, as the movable vane rotates, this rotation can be amplified by this optical arrangement. Such small rotation by the movable vane will cause a larger displacement of this spot of light on this scale.

So, by looking at the displacement of the spot of light on the scale, I can measure the angular rotation of the movable vane, which is the measure of the vacuum or the low pressure.

So, let me explain one more time, I have a chamber which is sealed and connected to the vacuum source which I am going to measure, within the chamber I have two fixed plates mounted. These two fixed plates are heated up at an exactly known temperature. The temperature of the movable vane is lower than the temperature of the fixed plates, and the temperature fixed plate as well as the temperature of the movable vane are exactly known.

So, two fixed plates have same temperature let us say T F and the movable vane has temperature let us say call it t v. So, T F is greater than T v. Now the gas molecules will be colliding randomly with the fixed plates as well as with the movable vane. Fixed plates, has higher temperature than the movable vane. So, when the gas particle rebound from the hotter plates, they will come back with the greater momentum than compared to the case when it rebounds from the colder vane.

So, this will impart and make momentum, which will cause the movable vane to rotate by some extent. This angular rotation is a measure of the pressure. This angular rotation can be amplified by optical lever arrangement. So, what do we do is, we send a beam of light and there is a mirror attached on the movable vane. So, a beam of light is sent to the mirror and a spot of light gets reflected from the mirror and falls on the scale that is attached.

So, small angular rotation will cause a large displacement of the spot of light on the scale. So, by measuring this displacement, I can measure the pressure. So, there is a formula available for this, this formula was derived by Knudsen himself.

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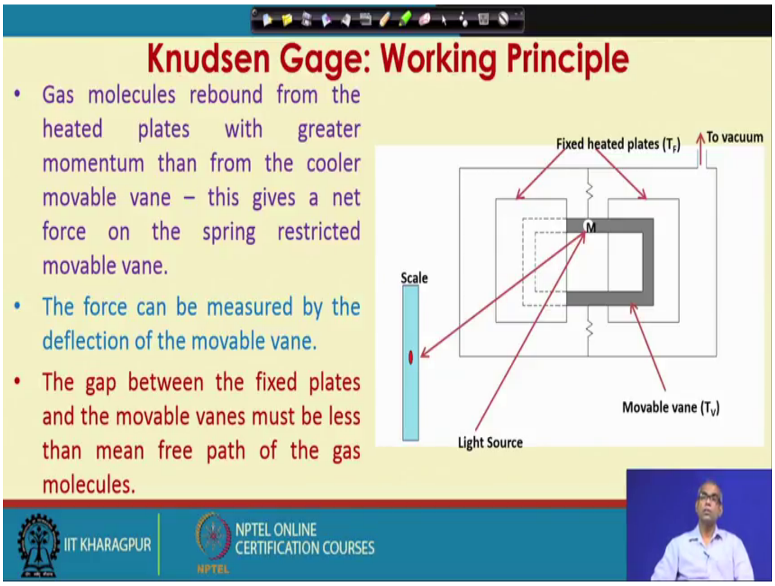

So, gas molecules rebound from the heated plates with greater momentum than from the cooler movable vane, this gives a net force on the spring restricted movable vane. The force can be measured by the deflection of the movable vane, the gap between the fixed plates and the movable vanes must be less than mean free path of the gas molecules, this is very important.

So, the gap between the two fixed plates and the movable vane must be very small, and this should be smaller or less than the mean free path of the gas molecules. Because of this condition we cannot use this instrument for the measurement of higher pressure; because the condition that the gap between the fixed plates will be smaller than the mean free path of gas molecules can be met only at very low pressures, because at low pressures the mean free path of the gas molecules will be lager compared to the case when I am talking about higher pressures. So, the relevant dimensions of the gage is less than the mean free path of the gas molecules.

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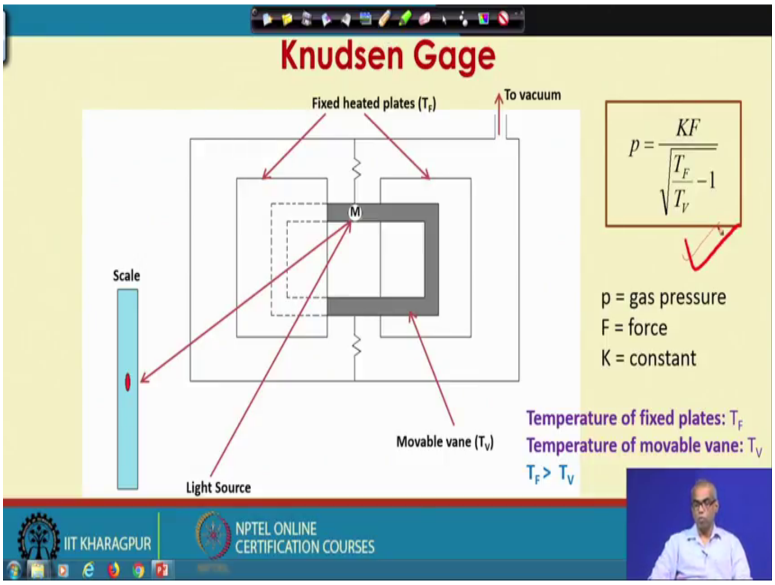

So, if this is the case that we have two fixed plates temperature T F and we have movable vanes temperature as T V. And T F is greater than T V then the pressure or the vacuum can be computed using this formula. P which is pressure is equal to K times F divided by square root of T F minus T V minus 1. Where small p is gas pressure capital F is force and K is constant for the Knudsen gage. T F is the temperature of the fixed plates and T V is the temperature of the movable vane. Note that the fixed plates can be heated up by an electric arrangement. So, you can install a heater to heat up the fixed plates, and we must measure the temperature of the fixed plates and the movable vane exactly.

This formula which can be used to measure the vacuum from known temperature of fixed plates and movable vane, and the force was derived by Knudsen.

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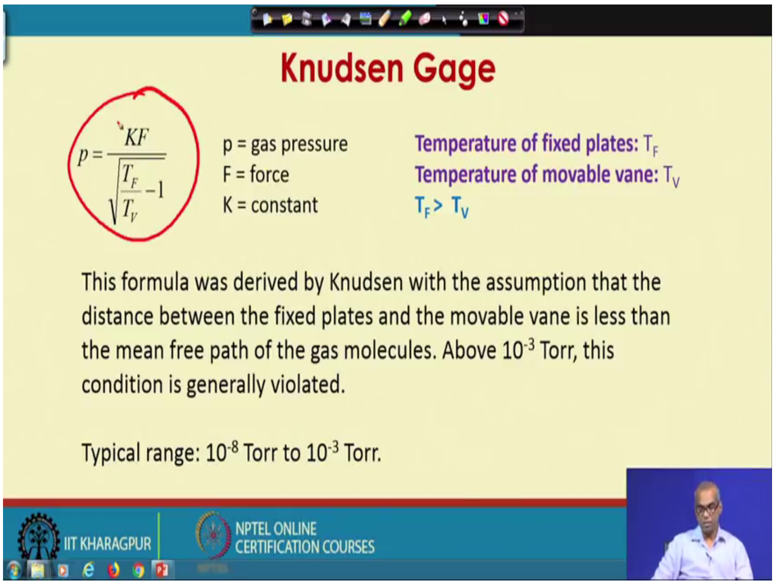

This formula was derived by Knudsen with the assumption that the distance between the fixed plates and the movable vane is less than the mean free path of the gas molecules. So, above 10 to the power minus 3 torr, this condition is generally violated. So, we cannot measure the pressure which is higher than 10 to the power minus 3 torr. Remember that one torr is 1 millimeter of mercury.

So, typical range of Knudsen gage is 10 to the power minus 8 torr to 10 to the power minus 3 torr, certain important points about Knudsen gage:

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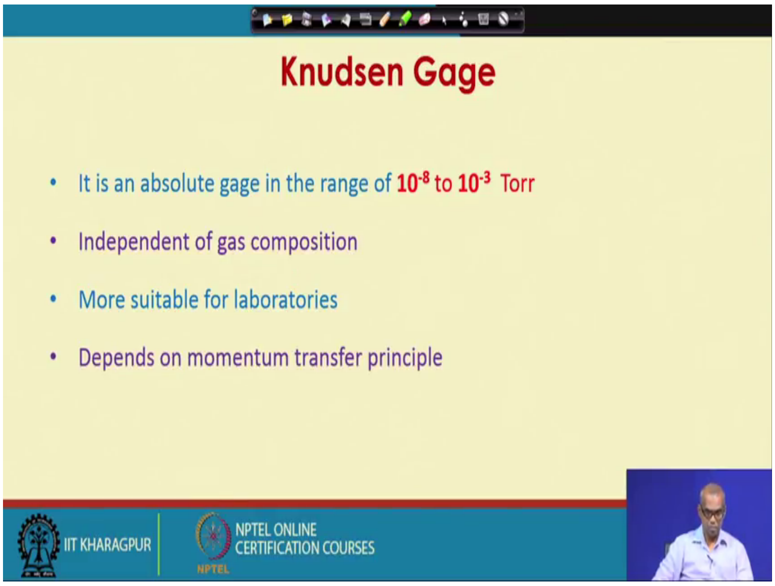

It is an absolute gage is the range of 10 to the power minus 8 torr to 10 to the power minus 3 torr; it is independent of gas composition. Please note that in the formula that will be used for measurement of pressure or computation of pressure, no information about the gas that is being used has been proved.

So, the pressure measurement is independent of gas composition. This is mostly suitable for laboratories it is generally not used in industry.

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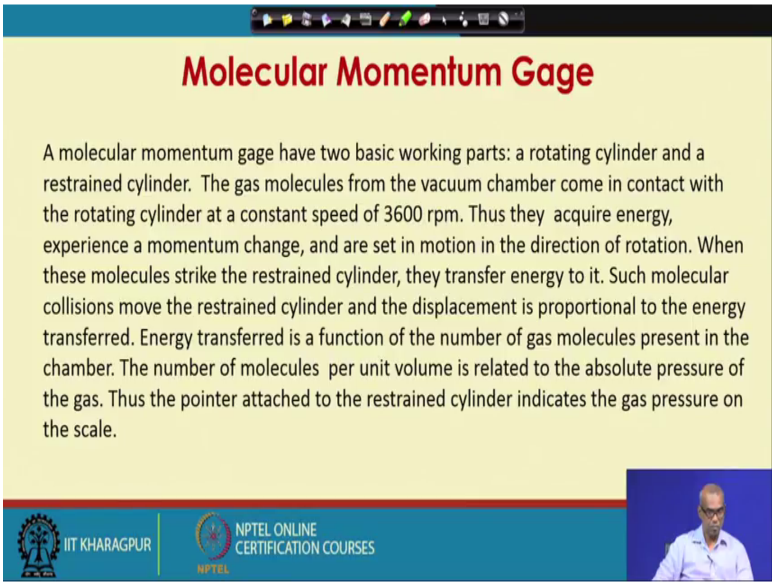

It depends of momentum transfer principle and Knudsen gage in the range it is used like 10 to the power minus 8 to 10 to the power minus 3 torr can also be used as a standard for calibration for other pressure measuring instrument in this particular range, that is 10 to the power minus 8 to 10 to the power minus 3 torr.

Now, let us talk about another vacuum gage known as molecular momentum gage. A molecular momentum gage have two basic working parts a rotating cylinder and a restrained cylinder. The gas molecules from the vacuum chamber come in contact with the rotating cylinder at a constant speed of 3600 rpm. Thus they acquire energy experience a momentum charge and are set in motion in the direction of rotation. When these molecules strike the restrained cylinder they transfer energy to it such molecular collisions move the restrained cylinder and the displacement is proportional to the energy transferred. Energy transferred is a function of the number of the gas molecules present in the chamber the number of molecules per unit volume is related to the absolute pressure of the gas. Thus the pointer attached to the restrained cylinder indicates the gas pressure on the scale.

So, in a way it has some similarity to the Knudsen gage, both works on momentum transfer. So, let me go through once again the working principle of molecular momentum gage. A molecular momentum gage have two basic working parts a rotating cylinder and a restrained cylinder. The gas molecules from the vacuum chamber come in contact with the rotating cylinder at a constant speed of 3600 rpm. Thus they acquire energy experience a momentum charge and are set in motion in the direction of rotation. When these molecules strike the restrained cylinder they transfer energy to it, such molecular collisions move the restrained cylinder and the displacement is proportional to the energy transferred. Energy transferred is a function of the number of the gas molecules present in the chamber. The number of molecules per unit volume is related to the absolute pressure of the gas, thus the pointer attached to the restrained cylinder indicates the gas pressure on the scale.

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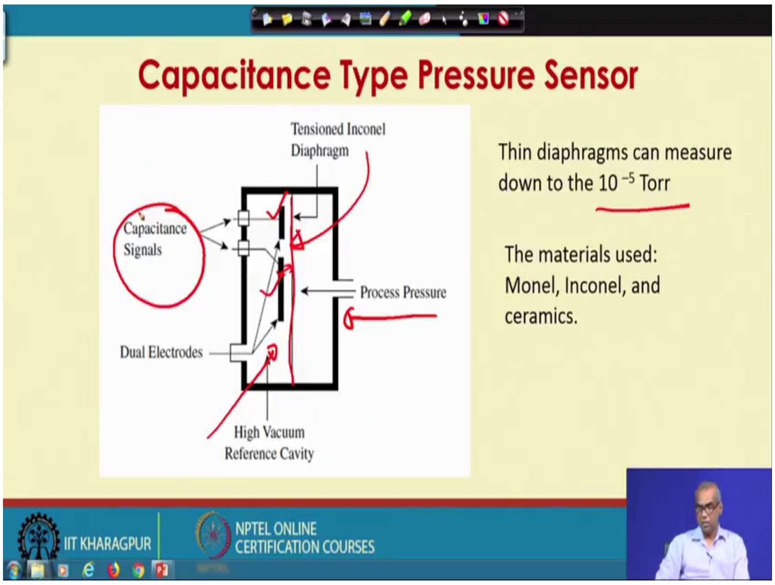

Capacitance type pressure sensor this consists of thin diaphragm and can measure pressure down to 10 to the power minus 5 torr. So, it consists of a tension diaphragm, the material use for making the diaphragm are monel, inconel, ceramics etcetera. Note that you have electrodes here and this is the thin diaphragm, thin tension diaphragm. This part let say we keep under high vacuum. Now when we apply pressure; that means, when this connected to the vacuum source, you will have the gap change. So, you will get an electrical signal as output. So, this way the capacitance type pressure sensor can measure low pressure upto 10 to the power minus 5 torr.

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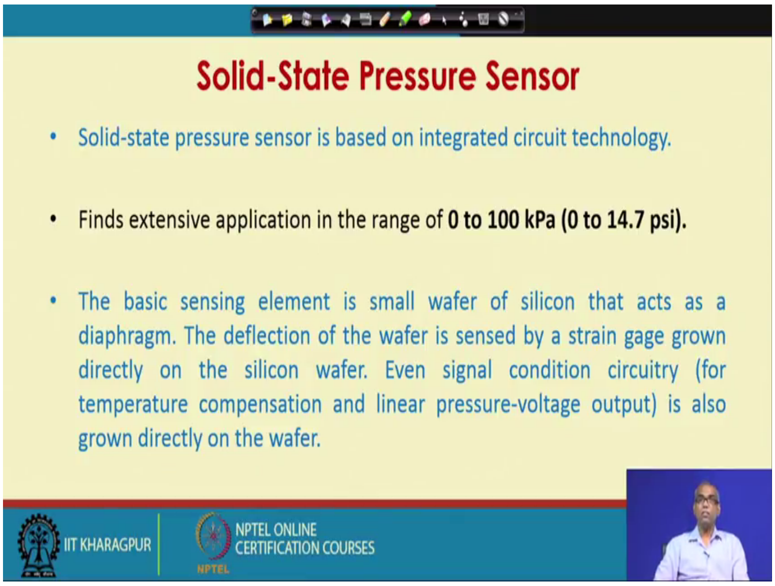

Next let us talk about a solid-state pressure sensor. Solid-state pressure sensor is based on integrated circuit technology. Finds extensive application in the range of 0 to 100 kilopascal, the basic sensing element is small wafer of silicon that acts as a diaphragm. The deflection of the wafer is sensed by a strain gage, grown directly on the silicon wafer. Even signal condition circuitry for say temperature compensation, and linear pressure voltage output is also grown directly on the wafer.

So, the solid state pressure sensor is based of integrated circuit technology, it is a new generation pressure sensor. So, the basic sensing element is nothing, but a thin wafer of silicon that acts as a diaphragm. So, diaphragm is the basic sensing element, and the diaphragm is made of a small wafer of silicon. Now if pressure is applied to the diaphragm you know the diaphragm will deflect. Just now we have seen the capacitive type pressure sensor.

So, this deflection of the diaphragm is a measure of the pressure. So, how do I measure the deflection of the pressure? One way to do that is to use a strain gage. We have talked about strain gage, when we talked about transducer elements. So, now, what we can do is, we can grow a strain gage directly on the silicon wafer. So, when the silicon wafer undergoes deflection the strain gage also undergoes strain.

So, it changes its resistance and an electrical signal will come out as output, which is a measure of the strain, which in turn is the measure of the deflection, which in turn is the measure of the pressure. In fact, what we can also do is we can grow the signal condition circuitry directly on the wafer. So, such signal conditioning circuit will be helpful for nullifying the effect of ambient temperature; that means, for temperature compensation as well as for making pressure voltage output linear.

So, the solid state pressure sensors are very advantageous, because they have this distinct features. It is based on an integrated circuit technology and just consists of a small wafer of a silicon, where you can grow the strain gage or and this signal conditioning circuits all together.

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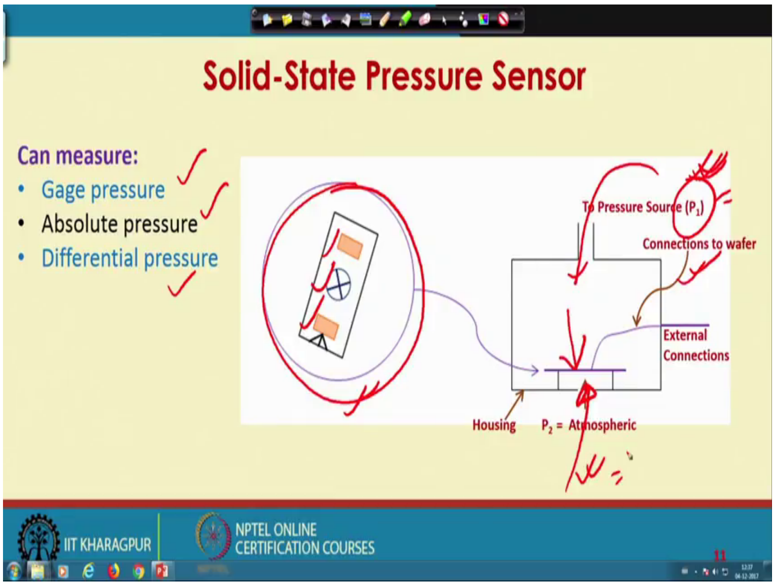

So, this can measure gage pressure absolute pressure as well as differential pressure. So, this is the silicon wafer, which acts as a diaphragm. So, see this is one pressure source, this is another pressure source, this maybe atmospheric pressure and then this is gage pressure is being measured. Now if you look at closely this silicon wafer, we have this. So, it is a silicon wafer where we have the strain gage and the other signal conditioning circuits, all grown on the silicon wafer. So, this is electrical connections to wafer.

So, as we apply pressure P 1 from here we apply pressure P 2 from here, the wafer undergoes deflection because of these differences of these two pressure, these deflection is sensed by the strain gage grown on the wafer and corresponding electrical output is noted. If these pressure is atmospheric pressure, we are measuring gage pressure, if this is sealed and completely evacuated we are measuring absolute pressure. So, you can measure gage pressure, absolute pressure, differential pressure or differential pressure these two pressure are different.

So, it is a very simple arrangement and very useful in the measurement of pressures in the range of 0 to 100 kilopascals, the main advantage is it gives you an electrical output simple in functioning and you can grow the strain gage as well as the electric signal conditioning electric circuits all on the diaphragm of silicon wafer itself.

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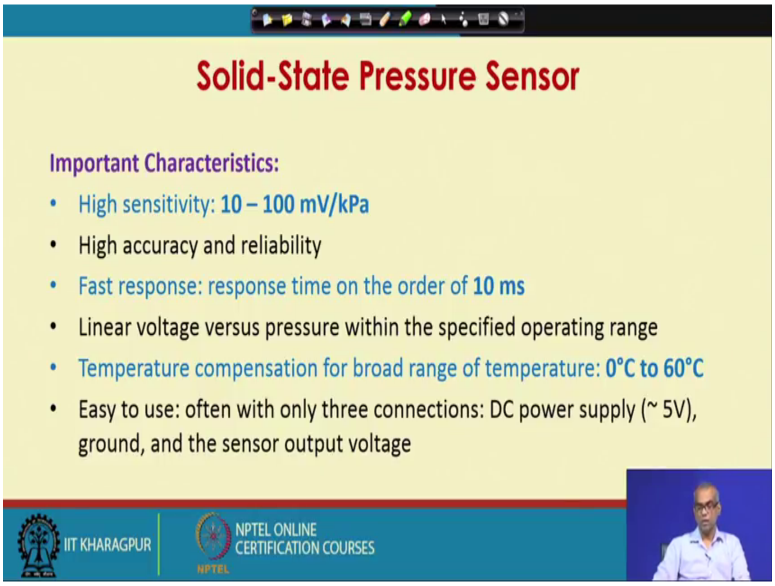

So, certain import characteristics of solid state pressure sensor it has very high sensitivity 10 to 100 millivolt per kilopascal, high accuracy and reliability, fast response time is on the order of 10 milliseconds, linear voltage versus pressure within the specified operating range.

Temperature compensation for broad range of temperature 0 degree celsius to 60 degree celsius, temperature compensation is available. It is easy to use often with only 3 connection dc power supply over 5 volts ground and the sensor output voltage. So, these important characteristics make solid state pressure sensor very useful pressure measuring instrument in the range of 0 to 100 kilopascals. It has high sensitivity high accuracy high reliability and above all its very simple to use gives electrical output.

So, we will stop our discussion here.