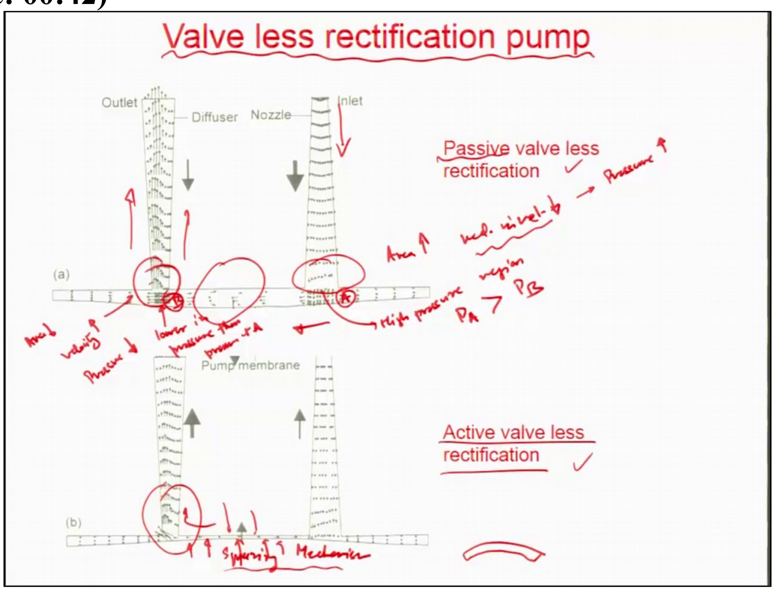
Design Practice - 2

Prof. Shantanu Bhattacharya
Department of Mechanical Engineering
Indian Institute of Technology-Kanpur

Lecture - 24
Different Types of Pumps and Sensors

Hello and welcome to this design practice to module 24 today we are going to talk about some of the different variants of principles associated to micro pumping and then delve into a little bit into the basics of one form of sensing which is sensing of gases using thin film elements and what are the basic principles involved in it.

(Refer Slide Time: 00:42)



So, let us talk about first micro pumps and I am going to show you a set of schematics and describe there and what happens so that you can realize. So, the first type of sort of a you know you can say a fluid actuator which is going to cause pumping comes in the form of valveless rectification pumps where there can be either a passive design or an active design. So, here in this particular case as you may realize that there is a change in the sectional area the cross-sectional area from the inlet side and the outlet side.

So, the inlet side is like a nozzle so the area suddenly increases and therefore the increase in area would signify a reduction in velocity okay. So, the continuum assumptions lead us to conclude that an increase in area should always reduce the average velocity of flow and therefore if the velocity again reduces through the knowledge equation the overall pressure would increase. So, there is a pressure rise and so therefore this is the high pressure region which is developed because the flow gets slowed down here okay it does not the velocity falls down here.

So, the velocity head is converted into the pressure head on the other side I have a diffuser arrangement where there is a lower cross-sectional area which eventually changes into a higher cross-sectional area. But because of this lower value of area the velocity head is more so area here is lower and velocity is increased because of that and therefore the pressure is reduced and so always I pressure at this point right here would be lower in comparison to point A.

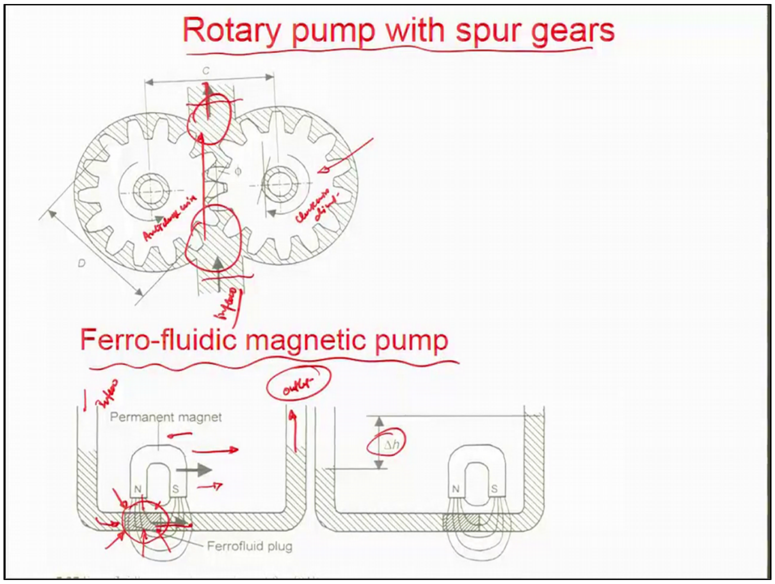
So, let us say this is B okay and this is A so lower in pressure than pressure at A. So, if PA in this particular case is greater than PB so obviously there is going to be a flow between PA and PB which is going to use out okay of this particular system and so by virtue of the architecture itself in a passive manner if we are gravity feeding the flow into such an inlet is going to come out on the other side and create a pressure head on the outlet.

So, these valves these these kind of principles are sort of you can say actuation principles based on fundamentals of reduction in area increase in velocity profile at different points along a channel and such architecture could be drawn to passively do some actuation in terms of fluid you know flow from one end to the other end by virtue of change in cross sectional area. A similar kind of a strategy can be done on an energized basis.

So, the passive part of this particular channel is now sort of made active through some kind of a squeezing mechanism. So, there is a vibrating disc for example just mounted below this channel where the disc bends you know in a worldly manner thus squeezing this particular part of the channel so that there is a throw out of fluid and so obviously the throw out would be more in this case because the pressure here is lower than the pressure here and so more fluid will be going into the outlet side than the inlet side.

So, this is one of the first systems of pumping that can get because of actuation being actively done or passively done or by change in architecture this is one example of fluid actuation.

(Refer Slide Time: 04:19)



The other example of fluid actuation is what you normally find through spur gears and rotary pumps with spur gears. So, here what has happened is that there is the inflow of fluid from this particular section and there are rotating and matching spur gears which are being rotated this one in the anti-clockwise direction and the other one in a clockwise direction. So, obviously the fluid would be transported from this end to the outlet side here.

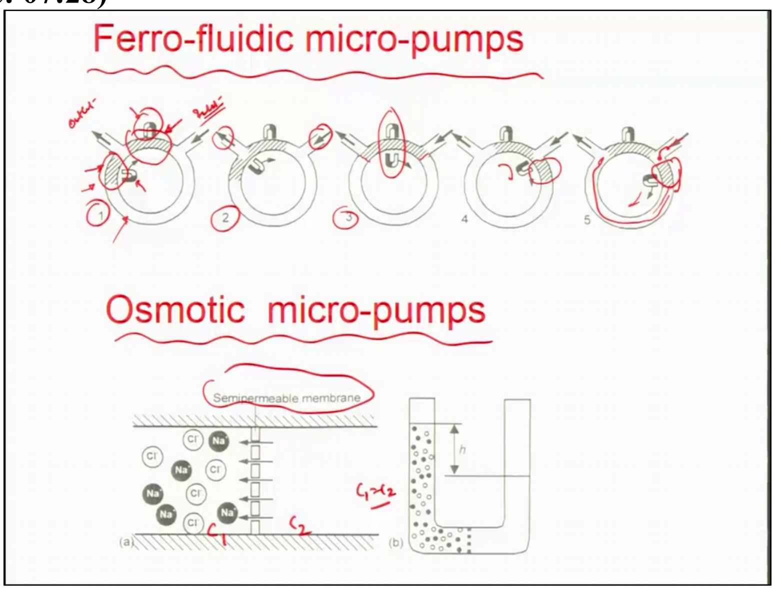
And the velocity would be increased because these teeth of the spur gears would act as pedals and forward flow and create more velocity as the fluid goes from this end the inlet end towards the outlet ended. So, therefore there is pumping mechanism based on it so this actuation is being done through small motors okay and we gets actuated. So, that it can pump across different domains there are Ferro fluidic magnetic pumps which are again based on a plug of fluid again which is comprised of some magnetic ferromagnetic material.

This could be for example of oil immersing iron oxide particles something like we does not mix through the overall water which is there in the system and it is activated as a plug you can see this hatched area here more acting like a plug and the idea is that when an external actuation is being done through magnetic field it magnetizes and as the magnet moves as this particular u-shape at horseshoe magnet is moved in a certain direction.

It drags along the plug along with it and so obviously if there is a water flow from this end let us say this is the inflow the water is actually taken by this plug motion because the plug will push the water column in upwardly manner on the other side that is the outlet side and it will pull in the fluid from the in fed or inflow side so that there is continuity maintained. And so the movement of this magnetic this this ferromagnetic material like a dispersion through an external magnetic actuation would allow for pumping to take place.

So, now obviously it depends on how fast the the motion is achieved by this particular magnet in one direction if supposing the the motion is faster in the forward direction and slower and the reverse direction that there would be a net pumping on the outlet side so on so forth. And so there is also a pressure difference which is being made by this technique which would lead to an outflow of the fluid. So, this is fellow fluidic actuation used through external magnetic fields.

(Refer Slide Time: 07:28)



Very intelligently the same principle can be designed in a circular route here you can consider instead of two horseshoe magnets one horseshoe magnet two horseshoe magnets moving in different directions. There is a inner magnet towards the inside of this loop. So, this actually is a channel loop with an inlet and an outlet. So, let us suppose this is the outlet part of the channel and this is the inlet part of the channel and there is continuous fluid flow through the in that part.

So, as we can see that there is a repositioning of the core horseshoe magnet with the flank horseshoe magnet from position one to further position two to further position three and so they come just exactly opposite to each other and this again has a sort of a pharoah fluidic pump which cirrhotic material which is shown by the the hatched lines in both these cases as the magnets are separate that is the core magnet is separate and the flank magnet is separate.

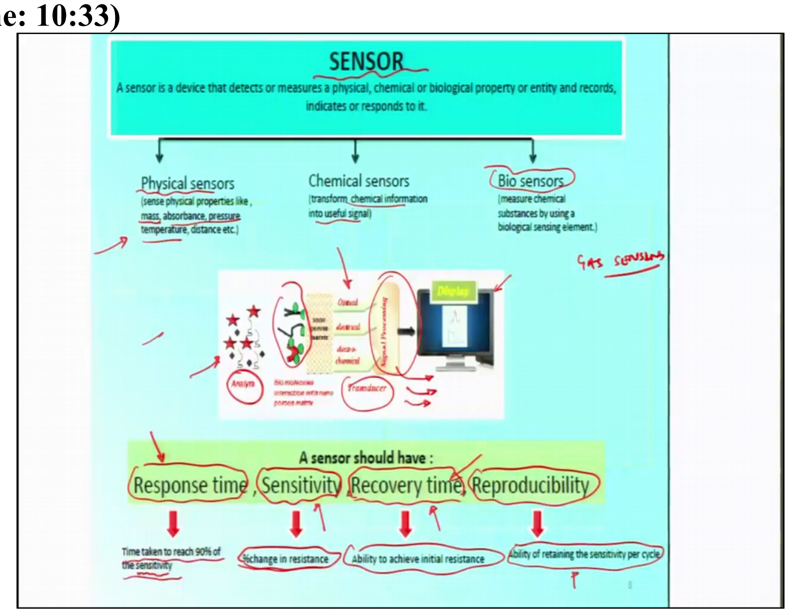
It attracts its own Ferro Florek material and as they come in face to face the material joins together as one particular plug okay. And from here when the motion starts the core magnet again starts going in a clockwise direction it starts separating one portion as a plug along with it which it drags along as this magnet moves this plug also moves and because the plug moves there is a pressure difference created here in which the inlet water can be fed in.

And let us suppose the whole cycle is repeated that this plug moves along with the mark the internal magnet of the core magnet to this position what is happening is that whatever fluid was actually in this particular space because of the motion of this plug is now going away whereas the new space that is being created is being filled with the new fluid. Again there is a joining action and this cycle continues many signs so, that fluid can be pumped from the inlet to the outlet side.

So, in a very intelligent manner with a two plug system this circular pumping station has been designed which would result in flows again. So, this is also magnetic actuation from distance. There are also osmotic micro pumps where there is a membrane across which there is you know diffusion of fluids so that concentration differences are eliminated and the membrane stops working after the concentration on both sides here c1 and c2 equalize to each other okay.

So, this is based on the concept of a semi permeable membrane and the membrane carries out the transport by the the osmotic pressure difference because of changed concentrations across two domains so this is again another form of you can say actuation mechanism which enables flows from one side to the other.

(Refer Slide Time: 10:33)



So, then we also look into a slightly different connotation so we have seen all the different kind of actuation mechanisms for causing flow actuations at the micro scale. We will now delve a little bit into sensor we already have done some useful illustrations about definitionally how we can put the sensor as really a transducer recognition element you know a sort of a signal processing system which takes up the electrical signal or the optical signal which is being generated and interpretation okay.

So, this is how typically you sensor is categorized and we also learned in our earlier exercises that there are physical sensors chemical sensors and biosensors based on what they are really sensing so if there is a physical property like mass or absorbance or pressure or temperature or distance which is being measured you you call it physical sensor. When you are able to transform the chemical information into useful signals it is called chemical sensors.

And if there are recognition elements which recognize only biologically active elements or biological elements so and effectively it measures those elements with the presence of those elements by chemical change which it transducers into a measurable signal a readable signal, it is called a bio sensor. So, typically given this basic definition which is a repeat of some of the earlier work being done what should a sensor have so one of the instances that a sensor should have is that particularly when we talk about the gas sensing business okay or in fact any other sensing business.

The first important point is the response time that when there is an analyte there is some object which the sensor is worthy of detecting how soon can it provide a transduced signal based on the presence of this analyte. So, this is one very important aspect the other aspect of course is sensitivity meaning thereby that what is the minimum concentration of the analyte that can generate a signal in this side of the sensor through the transduction process okay which is machine readable.

So, the sensitivity means the lowest analyte that can be sensed or the lowest quantum of the analyte that can be sensed okay by such a sensor. Then there is also a question of the sensor recovery time particularly in repeatable operations where you are doing multiple sensing you know modules together how soon the element can come to a state which is completely recovered which is completely baselined. So, that next measurement or next set of measurements can be carried out is the recovery time in gas sensing business is very important that once time and recovery times are short.

Because we are talking about some kind of an element which changes properties does some transduction on the presence or absence of certain molecules of gases and the idea is when the molecules would be not there in the system the sensor should be able to recondition itself back to its baseline value and ready for measurement for the next cycle when the molecules are present okay. so, it is very important that recovery times scales be shorter.

And then also there is reproducibility which is that in multiple runs how good is the signal which is coming out is it going to be similar if similar concentrations of the analytes are explored are there going to be any changes. And it really depends on this transduction process and the transducer itself that how that behaves with respect to the presence and absence of an analyte of interest.

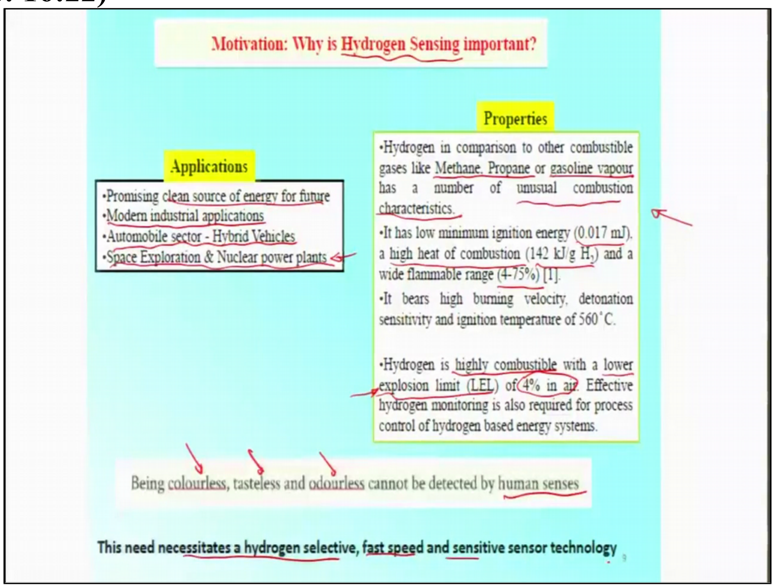
So, definitionally the response time is the time taken for reaching about 90% of the signal the final signal okay that is that comes out 90% of the signal is corresponding to whatever sensitivity levels are in the particular in the in the sensor. So, if sensor is able to measure ppm level of gases then the signal which is generated how fast for a certain amount of ppm let us say 100 ppm signal is able to attain 90% of its quantum and is able to plateau itself is going to be the response time.

So, in case of sensitivity particularly when we are talking about resistive elements in gas sensing there is a lot of utility of resistive elements which I will show you in the next slide there is a percentage change in resistance that we are looking at as the concentration varies so supposing we are trying to find this out through a system where we have a carrier gas and the target gas and we make a molar ratio in a manner so that there is ppm level of gas being injected into the system.

So, we want to find out that from zero concentration to that maximum ppm level that the gas is supposed to be what is going to be the percentage change the electrical change in the sensing element of the transduction element okay being what possibly change occurs okay which which leads to the enhanced sensitivity okay or which so what is the minimum percentage pain that is detectable that is what the idea is.

Then we have recovery time which is defined as the ability to achieve the initial resistance so I do not do that it is based lining the sensor. So, if we are talking about resistance is a property with changes which transducers it should come back to the baseline level so that it is ready for the next run. And then reproducibility is the ability to retain the sensitivity per cycle so whatever is lowest possible value we have been measuring should be repeatability being able to measure and that is how the robustness of the sensor comes into picture.

(Refer Slide Time: 16:22)



So, in case of gases it is probably very common to achieve gas sensing in terms of hydrogen concentration petrol then is a very inflammable gas and you know there are many systems through which hydrogen systems are carried a hydrogen sensing is carried out. For example in all the automobile sector hybrid vehicles which are having fuel cells would need continuous monitoring of the hydrogen level.

Hydrogen level is also being monitored in more or less all modern industrial applications other than you know is a clean source of energy for the future. For space exploration and nuclear power plants also sometimes hydrogen is used as a fuel and so it is a storage and it is reliability in supply and it is leakages and the losses therein are very highly needed or critically needed to be monitored and analyzed.

And now on the top of it the the fact remains that for a gas like hydrogen there are certain properties associated with the gases which otherwise cannot be detected by normal human presence. For example the gas is completely colorless or odorless or tasteless and so none of the human senses are able to detect if there is small hydrogen deep. But the the the disadvantage that this hydrogen has is that you know in comparison to some of the other combustible gases like methane propane or gasoline vapors.

Hydrogen particularly being lighter in weight also and having a low molecular weight has unusual combustion characteristics and it gets ignited very fast minimum ignition energy needed is only about 0.017 milli Joule and and thereby it results once it has been ignited in a very, very high heat of combustion on high heat of burning of the extent of about 142 kilo Joule per gram. And again white flammable range of 4 to 75%.

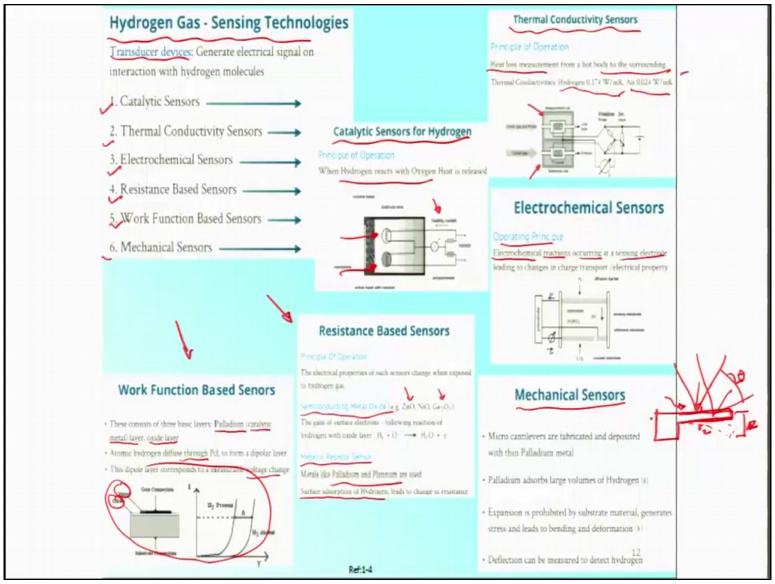
So, when we are talking about sensing sometimes it is a very common practice as we will see in most of the literature also to start with a gas like hydrogen which is really at the bottom of the the top of the pyramid in terms of its ignite ability or in terms of you know the kind of energy release that it would have in time. So, the criticality that it might need it the systems to be in once it leaks in certain systems like that.

The other very important point is hydrogen is a highly combustible gas with a almost a 4% in air being able to explode okay. So, only 4% by weight hydrogen if present in air is enough good enough to create an explosion. So, it has a comparatively lower explosion limit so we are actually doing sensing for something which is needed to have a high sensitivity of the sensor system which is investigating this particular gas okay.

And so therefore it is recommended that when a sensor system is designed although the applicability part is in question finally it may not lead to the detection of hydrogen but for the acid test and the test of robustness of the center it is important that such sensor should be amenable to hydrogen testing.

So, it basically necessitates hydrogen selective fast speed sensitive sensor technology let us look at some of the confluence of technologies which are there.

(Refer Slide Time: 20:04)



So, when we talk about the various associated technologies with respect to hydrogen gas and saying. There are a variety of different transduction options which are there and a lot of devices we generate signals electrical signals or interaction with hydrogen molecules. For example look at catalytic sensors, thermal conductivity based sensors, electro chemical sensors resistance based sensors work function based sensors and mechanical sensors.

These are some of the few most widely used ones when we talk about hydrogen gas detection particularly increase levels or in lower concentration levels. So, what the catalytic sensors for hydrogen typically means that you are burning hydrogen in the presence of oxygen and measuring the heat release. And so if we have a standard hydrogen so basically in this particular case we compare a known concentration of hydrogen and the heat that it leases with respect to the unknown concentration of hydrogen in two different modules here right here.

And with that we try to look at what is going to be the concentration of hydrogen that is being measured or is there really hydrogen that is being measured or something else. So, these are one set of sensing techniques the other is again thermal conductivity sensors again the transducer element here is measuring the heat loss from a hot body to the surroundings. And there are two different bulbs in this particular case.

One of them is the reference and another is the measurable sample and we know that thermal conductivity of hydrogen is about 0.174 watt per meter Kelvin and that of air is 0.024 watt per meter Kelvin. And so with this in mind if we are able to measure the thermal conductivity of a certain gas mix we can see or we can do the bulk modeling to see how much hydrogen is present in what percentage of air and that way we can find out the concentration of the hydrogen.

Then there are of course electrochemical sensors which operate on the basis of electrochemical reactions I doggedness a gas which is bubbled in as you know in a standard hydrogen electrode as well and it creates a reaction where one you know dissimilar level concentration of an electrolyte is maintained massive electrolyte is maintained with the Platinum electrode. And it basically gives out a voltage response of about 4.02 volts.

And so therefore as the concentration of hydrogen is changed that is bubbled readily through this particular fluid it shifts the equilibrium to a point where it will start giving even more voltage or lesser voltage and based on that you could see what is the percentage hydrogen in the air that you are sending in so in any even hydrogen is being loaded into something and sent. So, when we are talking about sensing hydrogen in air basically it is not hydrogen alone but a lot of other constitutional which are present.

And we are specifically trying to customize the response to only the hydrogen which is there and not the other molecules which are there. So, therefore there is an aspect of specificity that how specific a sensor would be in terms of recognizing only one gas over the others. And so in props and these resistance based sensors which are one of the most widely used sensors particularly when we talk about gas sensing.

So, their principle of operation is that in the presence of hydrogen specific change in the resistance happens because of formation of hydrides or states which have a very specific value of resistivity. So, when we are talking about sensing elements like palladium or platinum which are very heavily used for monitoring of hydrogen in the presence of hydrogen they will have the palladium hydride or the platinum hydride which actually have different resistivity in comparison to their pure states.

And because of that any such distance change could be calibrated with respect to what is the hydrogen being absorbed on a particular surface and the absorbed hydrogen is a function of what is there in the ambience or the air around which around around the particular element sensing element. So, there are either metallic resistance sensors like palladium and platinum or which work on the business of surface absorbed hydrogen leading to a change in electrical resistance.

Or there are semiconducting metal oxides like zinc oxide or germanium oxide tungsten oxide etc., which works on the principle that there are defect states on these oxides which would get equilibrated with the hydrogen because it is reducing in nature. And it will result in the change in the bandgap because the electron that is there would be released okay and the oxygen defect which is present will release an electron will go and react with the reducing gas which is there okay in the the ambience.

And so therefore there is an abundance of one particular charge carrier type in zinc oxide case it is the N type carrier which would suddenly increase and this would lead to a reduction in the resistance because obviously the mobility and currents are directly related if the charge carriers are more then the mobility of such carriers are also more and it will result in lower resistance in the material semiconducting material.

So, these are resistance based sensors there are also work function based sensors which consist of three basic layers one let us say is a palladium catalytic metal layer there is an oxide layer and when atomic hydrogen diffuses through the palladium to form a dipolar layer. The dipole layer corresponds to a measurable voltage change as can be seen here this is the metal layer this is the oxide layer which is there and the metal layer is present over the oxide layer.

And we are talking about just a dipole formation due to which there is a change in the voltages between the metal layer and the oxide layer. There are also mechanical sensors which would be used in doing hydrogen gas sensing. One of the most important mechanical sensors are micro cantilever sensors which are based on again the principle of differential surface absorption. So, if you have reactions being carried out on two surfaces with different surface energies Sigma 1 and Sigma 2.

This sensor will automatically bend because of such a difference according to the theory proposed by Stoney. And so this kind of a band which is probably Delta Z can be recorded in terms of a beam which gets deflected from the surface reflected from the surface and such bending of theta would result in finally a change in the angle of the beam corresponding to 2 theta okay.

So, definitely the mechanical motion of a cantilever if it can be measured one can find out how good or bad the surface is with respect to hydrogen. And some particular specific film which absorbs hydrogen on a very sensitive basis can be suitably applied so that the cantilever movement can give you an idea of what is the percentage absorption of the hydrogen on the surface.

So, you could tailor this film in a manner so that it does not react or absorb to any other species but only hydrogen and there are quite a bit of materials which would be very specific to hydrogen and not so specific to other gases which are in picture. And so when we talk about designing a sensor for any other gas we would need to remember this then in order to address the specificity issue the basic recognition element there which was there in case of hydrogen will need to be changed okay in if the if the gas is different.

So, that is how different principles are across which gas sensing is carried out I look into a few more slides probably in one of the next lectures where we will discuss in details about some of the strategies which have been done a research level by our team as well to design such gas sensors in the interest of time I am going to close this particular module, thank you very much.