Introduction to Industry 4.0 and Industrial Internet of Things
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Lecture – 27
Key Enablers of Industrial IOT: Sensing-Part 2

In the previous lecture on Sensing; that means, sensing part 1. We have gone through the use of different types of sensors, for different industrial applications. We have seen sensors such as temperature sensor, accelerometer sensor, gas sensor, there could be different other several different types of sensors. And in typical factory smart factories we are talking about the use of large number of different variants of different different types of sensors.

The beauty about this sensors is that particularly for industrial applications not only they are supposed to sense, whatever they have been made to sense, but also they will have to with stand the harsh environmental conditions they will have to withstand so they have to be robust enough. They have to be robust enough to withstand the harsh environmental condition the industrial conditions in which they are going to be deployed.

Keeping that aside, we have also seen that as I told you in the previous lecture that; the designing and fabrication of a sensor is a multi month multiyear program. And it is a completely different ball game if you are trying to come up with a sensor for the first time. Those who have already up with a design and it is a well tested well proven principle that is simpler. Basically, in all we need to do is once you have a proven concept you take it and you go for mass production.

But for the first time if you are coming up with a unique type of sensor the designing of it and fabrication of it is quite complex and is typically done by researchers, who take interest in micro-electronics, sensor fabrication, and so on that is completely different. But I thought that let me give you a brief idea about one of the sensors the gas sensor. Along with a colleague we have taken interest in IIT Kharagpur to built gas sensors and deploy them for monitoring the air quality.

So, in this particular lecture I am going to run you through this kind of sensor, the efforts that we are taking. And taking together basically as I told you that the experts is completely different, that is required to come up with a gas sensor. So, I am going to talk about the working principle of a gas sensor and then I am going to take you to one of labs of one of my colleagues, who is basically fabricating a gas sensor at IIT Kharagpur.

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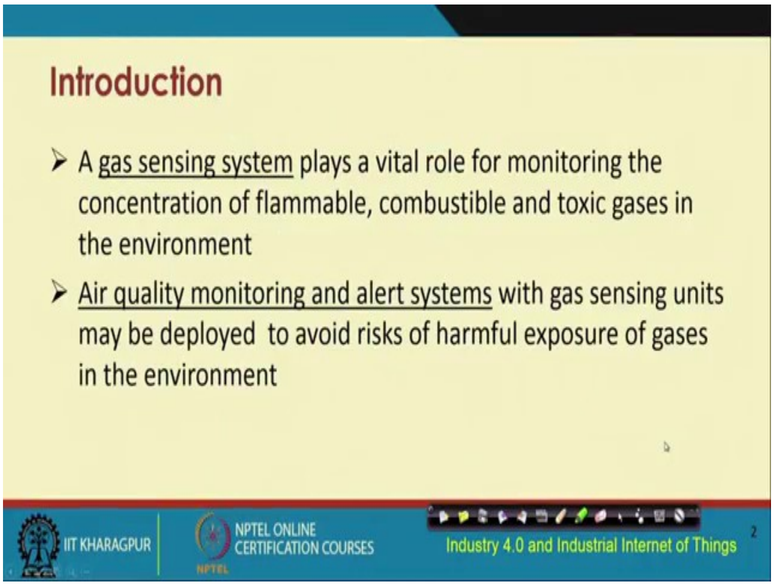

A gas sensor basically plays a vital role for monitoring the concentration of flammable combustible toxic gases in the environment. Gases such as methane, NOx gases.

SOx gases, these are toxic and are very dangerous gases so; they will have to be detected monitored continuously. If we are talking about air quality; air quality monitoring is very important in today's world; because the entire world throughout the entire world somewhere less somewhere more the air quality has degraded, due to the emission of lot of harmful gases into the environment.

So these, quality of the concentration of the different gases harmful gases like NOx gases SOx gases, etcetera, methane etcetera, these will have to be monitored continuously. So, as not to risk the individuals the humans living on the earth, and other organisms living on the earth. So, as not to harm these individuals from exposure to these harmful gases, that are emitted in the environment by different automobiles.

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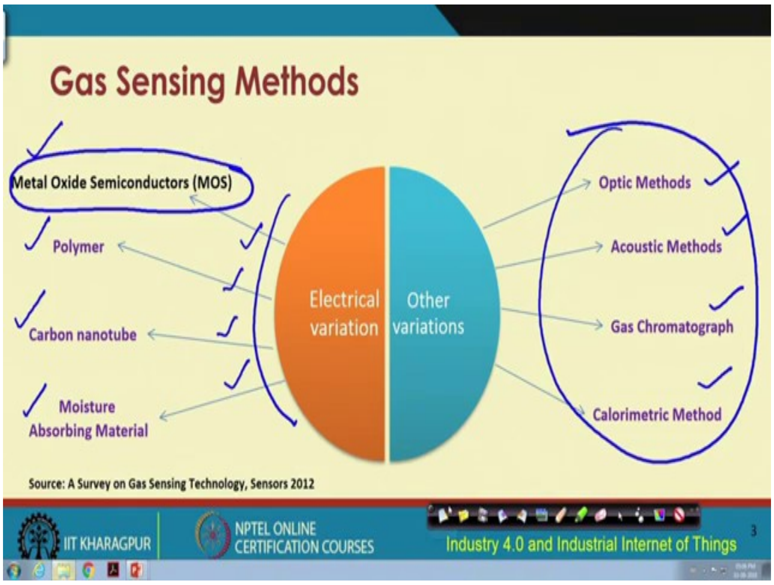

So, there are different methods for gas sensing. Gas sensing basically can be done with the help of optical methods, acoustic methods, chromatographic methods, calorimetric methods, can be done with moisture absorbing materials, carbon nanotube-based materials, polymer materials, and metal oxide semiconductor materials. These one's basically are the electrical variants; that means, that these type of gas sensing methods like this one's, they look at the change in the electrical properties of the environment where these different gases are.

Changes in electrical properties like changes in the current characteristics, changes in the voltage characteristics, changes in the resistive, characteristics of the material the environment, where these harmful gases are the concentration are rising raising. And these then basically sent these different signals, in the form of resistance value or resistance or current or voltage or whatever these methods basically are they different other methods.

So, we will look at in little bit more detail about how to fabricate a metal oxide semiconductor based gas sensor because that is the facility that, we have in our campus. And I can brief you little bit about this particular method of metal oxide semiconductor based gas sensing.

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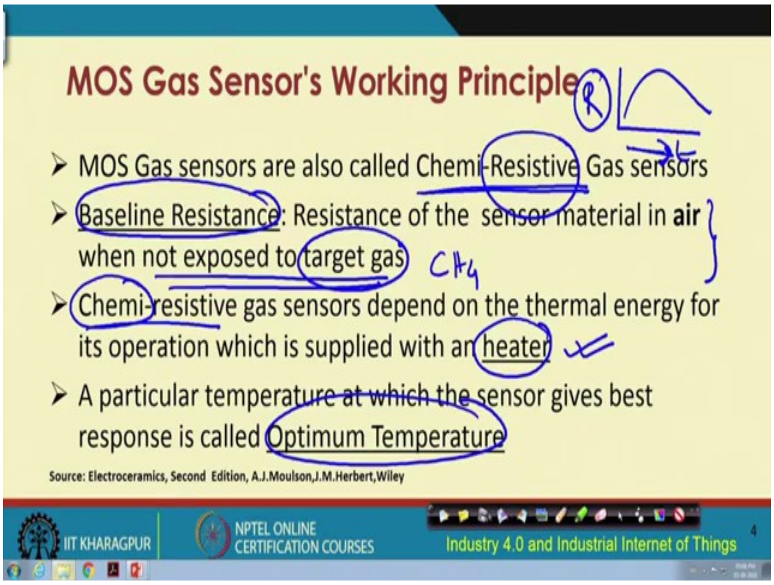

So, this is this MOS gas sensors working principle. This MOS gas sensors are chemi-resistive gas sensors. Chemi-resistive means; like there is some chemical reaction that happens with the sensor material that is there. Because of which the resistive property of that material will change. And what is required is to measure this resistive property with changes in something may be change with time or, whatever.

You get the change in the resistive property of that particular material when the concentration of the gas increases. So that means, that you need to have specific selected materials for targeting specific gases it is not like one material will be able to sense large number of different types of gases it is not like that. So, these are basically selective materials for selective gases. And these selective materials will have the change in the resistive properties, with the with the change in time or change in temperature or whatever.

So, basically we need to understand this chemi-resistive property, but before that we need to understand the concept of the baseline resistance. This is basically the resistance of the sensor material in air when it is not exposed to the target gas. So, this target gas could be let us say methane. So, when it is not exposed to methane, what is the baseline resistance? This is something that is required to be calculated or you need to have this information.

And then these chemi-resistive gas sensors will depend on the thermal energy for it is operation which is basically supplied through some heater. Because this chemical reaction will have to take place for which the heater will heat up that particular material and then that will help in changing the resistive property. So, a particular temperature at which the sensor gives the best response will have to be taken that is optimum temperature.

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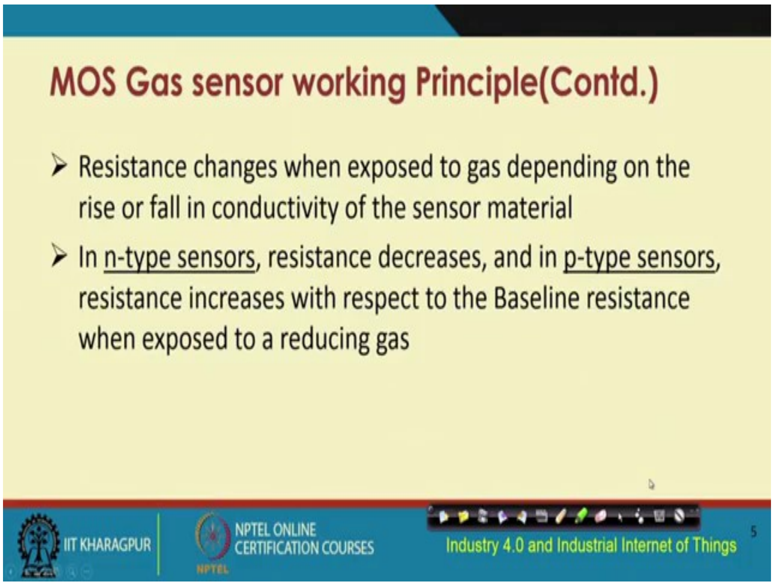

So, the resistance value basically changes when the material is exposed to gas depending on the rise or fall in conductivity of the sensor material. So, it is a choice of the particular material is very important depending on the gas that is being targeted to be sensed. So, in n-type sensors basically the resistance increases and in p-type sensors the resistance increases, sorry. In n-type sensors the resistance decreases and in p-type sensors the resistance increases with respect to the baseline resistance when that particular material is exposed to a target gas.

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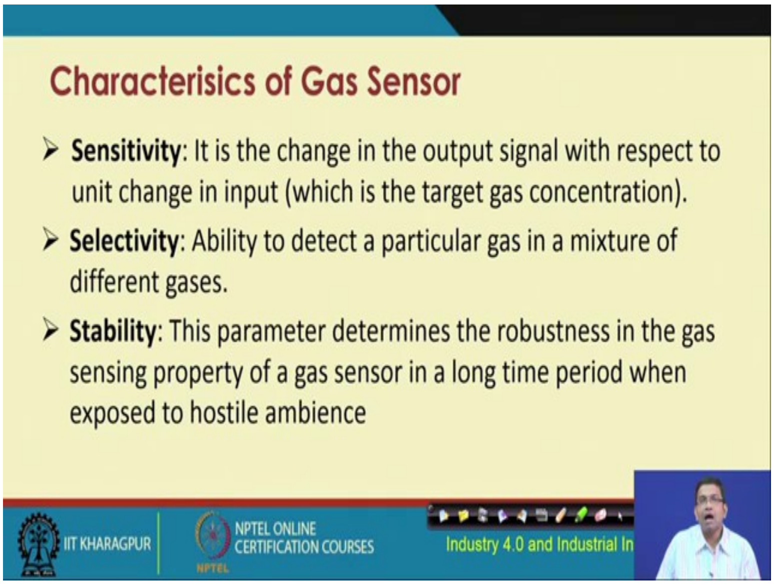

So, there are different characteristics of the gas sensor changes in the sensitivity; that means, it is the change in the output signal, with respect to the unit change in the input. Input means the target gas concentration. If you are changing the target gas concentration unit concentration change, how much is the unit change in the output signal, with respect to it.

Selectivity is the ability to detect a particular gas in a mixture of different gases. Stability characteristic is basically the parameter, which determines the robustness in the gas sensing property of a gas sensor in a long duration of time, when it is exposed to hostile ambience.

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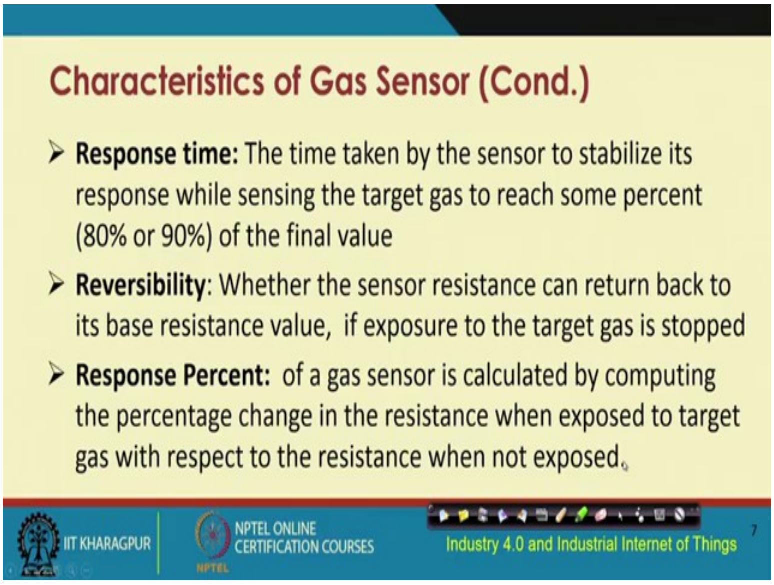

Response time is the other characteristic, which basically captures the time taken by the sensor to stabilize it is response, when sensing the target gas to reach some percentage some predefined threshold pre configured value like; 80 percent 90 percent or whatever. So, how much is the time taken to come to that stable point, that is the response time.

Reversibility is whether the sensor resistance can return back to it is base resistance value; if you stop the exposure of the target material to the target gas. And the response percent is the parameter, which is calculated by computing the percentage change in the resistance, when exposed to target gas with respect to the resistance when it is not exposed. So, resistance when it is not exposed verses this thing that is the response percent.

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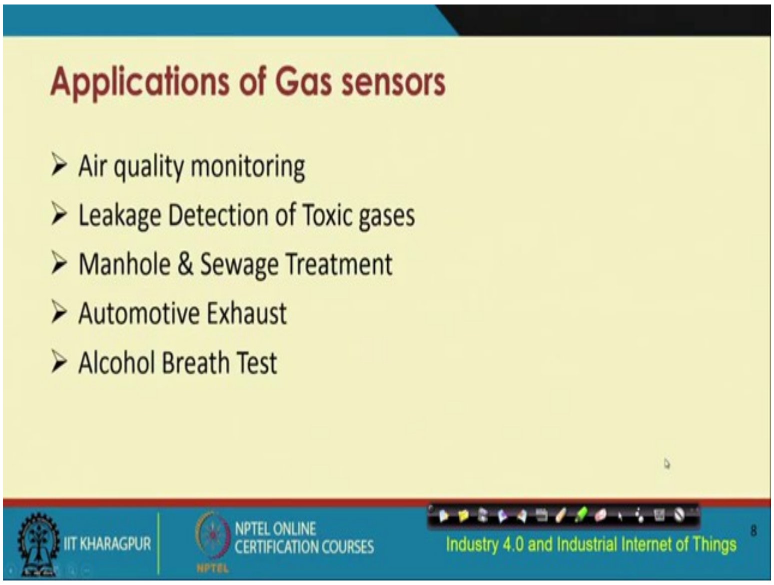

So, gas sensors find different applications; what I was telling you is air quality monitoring. Likewise, it could be used this sensors could be used for leakage detection of toxic gases. If leakage detection of LPG pipes, manhole or sewage treatments plans, gas sensors are commonly used. Automotive exhausts also used lot of gas sensors different types, alcohol breath test also use gas sensor.

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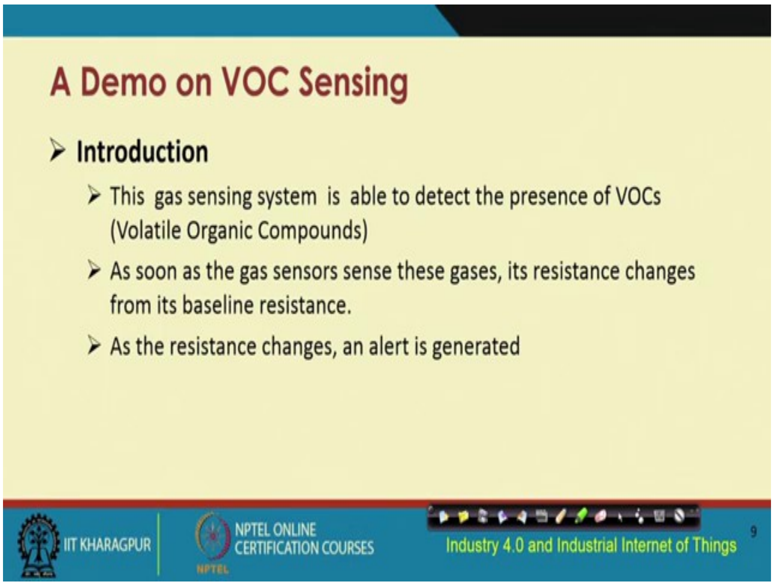

So, I am going to show you the demo of one of this sensors, which is based on it is a gas sensor, which is able to detect the presence of volatile organic compounds. So, as soon as basically in this kind of sensors as soon as the gas sensors senses, this gases, their resistive capacities their resistive properties change with respect to the baseline resistance; that means, when the resistance value when this gas sensors are not exposed the target gas. So, as the resistance changes basically alerts are generated, if a certain threshold is crossed.

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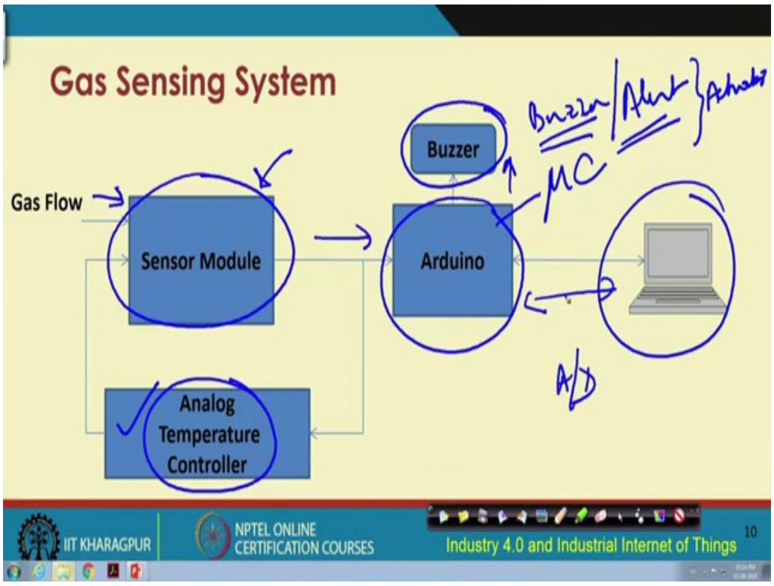

This is the overall block diagram of a gas sensing system. We have this sensor module, which will have this sensing material for a particular target gas. So, gas basically is passed through this particular sensor module and this material is chosen in such a way that it is going to change it is resistive properties with respect to the concentration increase in concentration of the chosen gas.

Then you have the analog temperature controller, which will basically monitor or control the temperature variation. Because I told you that we need to have some heater in order to start this chemical processes of this materials when the gas is pass through them. So, that the controlling of this temperature is done through this particular controller, the analog temperature controller.

Then you have some kind of a micro-controller, which will help in doing some processing of the data the analog or the digital data that comes in to the micro-controller. And then some kind of alert like some buzzer or something could be used in order to generate the alert. So, this will be like an actuator. And then you also have kind of PC, which will help you in the overall monitoring and processing it could be a PC or a laptop or, anything any other computational device.

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We are actually right now in the gas sensing facility lab of the Material Science Centre of IIT Kharagpur. This particular lab is lead by Professor Subhasish Basu Majumder. So, I have with me Professor Basu Majumder; Professor Majumder Basu Majumder would you please tell me what are the facilities in this particular gas sensing facility lab.

In fact, the lab was developed to test a variety of gas sensing materials. So, as that the gas sensing materials are characterized first in terms of it is porosity and semiconducting properties. So, once you have the material ready, then you will have to characterize them in order to know that; what is a gas sensing capability. So, we have fabricated a sensing facility which we call a dynamic flow gas sensing facility, because the gases are flowing.

So, it starts with this kind of different types of gas we actually procure from outside. And the idea is to make say air-quality monitoring that is one of the examples or you can sense various types of toxic gases as well. So, at present our lab is interested to measure the sensing facility of hydrogen that you can see and various toxic gases like carbon monoxide methane, then NOx. And recently we where started working on; carbon dioxide for breathe sensing development, breathe sensor development.

So, it starts with variety of gas and there is a provision for you to mix the gas also. So, gases are transported, so it is having a many fold their. So, you can select that which gas chamber will be connected to the sensing chamber. So, we will have to move from this place to the other side of the lab.

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And so the gases that are coming from the many fold there are four different lines. And one exclusively we use for the carrier gas and in most of the instances the carrier gas is here, which is having 20 percent of oxygen and a variety of test gas. So, this gas controlled this gas they are controlled by this mass flow controller. And at present there are three mass flow controller and we can add 1 or 2 more and this is controlled by this controller.

So, the flow rate of this gases you can controlled either manually or through software. And this past through a hygrometry chamber, so you use different types of solutions to maintain the humidity of this gas. So, either you can test this gas in dry condition or, you can put your own humidity to see the effect of gas plus humidity. And this flows through a several walls are there so it passes, through this kind of line so, which is the input line of the sensor chamber.

So, we put our sensing element inside this chamber and I can just take it off the first part and you can see that there is a small substrate here and this is connected with two probe. And later I will show you the type of sensor that we developed and just at the point of this base we have a thermocouple, we can precisely monitor the temperature of the sensing chamber itself. And by controlling this mass flow rate of these gases we can precisely control that, what will be the PPM level of this gases inside this chamber. So, this is block initially, although it is not being operated now.

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But if you just fix this one so it is a gas proof chamber with a heater embedded at the bottom; so, we can precisely change the temperature and your sensor remains there. And two probe on the surface of the sensor, they take the resistance value as a function of this gas concentration or, as a function of temperature. So, there is a temperature controller. So, in one kind of measurement, I can keep the temperature of the sensor constant, so we call it as a isothermal condition, and then change the gas concentration.

So, that is one set of measurement and we measure the surface resistance of the sensor, as a function of time so this is one type of measurement. The second type of measurement is that you keep your gas concentration constant and vary the temperature. So, as a function of temperature, you can measure the same set of resistance transient. And if you want to make this system complicated, then you can add humidity into it. So, you want to know that at humidity level that how this gas sensing is being performed. So, these three measurements are done for each of these samples and on top of that you can now modify your samples.

For example, you start with zinc oxide, then you can add indium into it. So, see what kind of vacancies are there in inside this material and how the gas sensing is changed by porosity or, by defect concentration. So, there are there is a once you get this resistance transient value, as a function of temperature, as a function of concentration, or, as a temperature of humidity. Then you have a wide full of data, and we do lot of data analysis of the resistance transient, and we have dedicated equipments for those kind of measurement, and the basic measurement that we do with an electrometer.

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So, we have two electrometer here, one is a source measure unit and another one is a very high resistive measurement type electrometer. So, usually we use this electrometer to measure the transient that is the base data that we measure so these are all dc measurements. So, we have the capability to go for AC measurements. So, we can do the impedance spectroscopy, by this impedance analyzer and that will tell us that; what is the difference between; a DC measurement and AC measurement.

And we can analyse our data perfectly, because sometimes we use the data in the time zone or sometime we use the data in frequency zone, so just by Fourier transform. So, this gives us lot of flexibility to understand this gas sensing material and I will show you some of the graphs that typical graphs which we can think of. So, this part is quite useful, both this resistance measurement and this transient measurement.

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And also we have another network analyser, which basically we use for noise spectroscopy, because sometimes are noise inside the resistance transient that also gives lot of information. This is not very frequently used, but this gives very very exceptionally high quality data as per as understanding of the types of gases concerned. Because basically when you measure the resistance versus time the data is more or less very monotonous.

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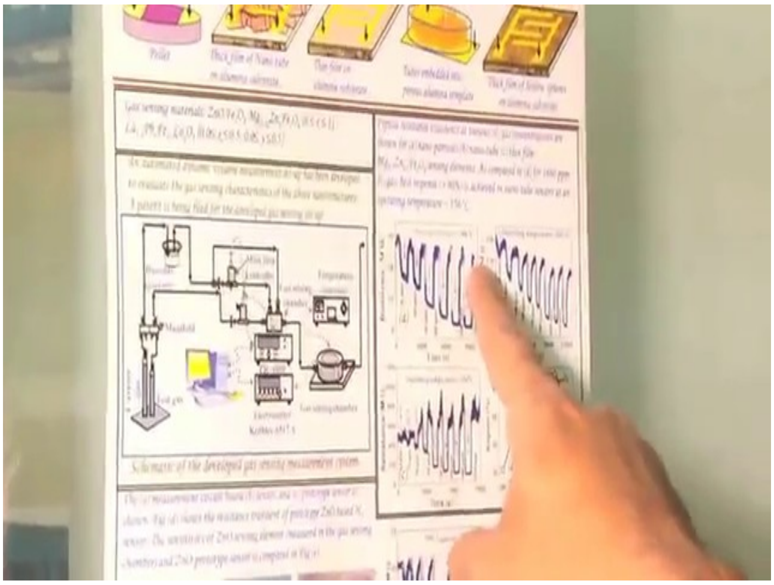

When you pass gas then the resistance changes and depending on the concentration of the gas the resistance changes more. So, you can calculate the response percent from this transient data that how much is this change resistance in air and resistance in gas. So, it is R a minus R g by R a so you can calculate what is the response percent. How much time does it take to this kind of fault typically according the SDM specification?

The fall 90 percent of this resistance at each concentration of the gas so that is your response time. Similarly, when it comes back from this resistance to the base resistance so that is your recovery time. So, this are the basic data of whatever we get that is response time then response percent. So, when you do as a function of temperature, then as you can see that not at all temperature it as similar kind of response percent.

So, depending on the concentration of the gas whatever you are using, and the temperature operating temperature of the sensing material, you have this kind of bell shaped curve and this also gives us lot of information. So, I think we can explain it better, but it is a time consuming process. So, we have to learn lot of things to understand to these basic features.

But once you get this kind of data it will be interesting for you to know, that the type of sample that the morphology of the sample as immense influence on this kind of data, which is one good part because you can do a one to one structure and property correlations. This particular poster you show it is being showed that you have a powder you make a pullet out of it make two electrode and then measure this resistance.

And change your sample configuration from here to a nanotube kind of thing or a basic thin film, or a embedded nanostructure, or a thick hollow frame nanostructure, these are all schematically drawn and one to one correlation you can get in the upper micro structure. You see that this is just like a pallet this kind of powder with having a porosity the tube exactly it forms a hollow tube. And suddenly the gas will defuse inside also absorbed outside so response percent is very fantastically high here.

Similarly, you have nano-rod thin film this is interesting embedded nano-duo structure already the base is some kind of porous material and we packed this kind of tubes inside and put one electrode here and one electrode there. So, in that case it is a parallel kind of plate configuration we are using sometimes we get surface type of electrode we deposit. So, once you do this kind of nano structuring the same material, same gas concentration, same humidity, same temperature, but you get dramatically improved gas sensing performance.

So, the whole idea of this type of dynamic analysis is to understand your material modification of your material for a particular purpose. In order to make it selective we also do another type of material prepare whatever we do that is nothing, but materials engineering. The same zinc oxide it can sense all the gases or by sudden modification, I can make it, selective for hydrogen selective for NOx.

So, this is a tremendous materials engineering we do in this lab and we get a selective sensor. So, once we get the selective sensor then the idea is to pack the selective sensor in the form of indigenous sensing element, that was developed by our M Tech students. So, this kind of sensing element, and then separately we will have to define a electronic circuit module, so that this can be connected with the circuit module. And whatever this all this instruments are doing.

In fact, that will lead to a portable sensor so you can carry this sensor module. So, our job is mostly to manipulate the materials check their sensing properties. But somebody should make this sensor also to make a prototype, so that we can take it outside hang it somewhere so some kind of arrangement was made, so that is quite rudimentary. But this kind of arrangement was made, and you can hang it on your wall, and then you put a room fragrance in the wall and in principle it will do the characteristics. I mean we will do the sensing.

Now, one important aspect of this kind of dynamic measurement is that in real ambient this flow is will not be there. So, the flow whatever we are getting so whether this is say 20 SCCM or 100 SCCM or 500 SCCM. So, you are drawing lot of oxygen on to your sensing surface. And when the gases senses, the sensing product develops, and you are driving get out. So, you get a very characteristic response and recovery plot out of this measurement. But your actual sensor whenever it will be hang somewhere, there will hardly any flow. So, we will have to device we had have a device a static chamber. A static chamber where you just put the sensor put some gas and allow it to sense and then automatically it gets recovered. So, that challenge we took when we understood this material well and this part whatever you are saying. So, much equipment etcetera, everything was by passed and we have our own micro-controller best circuitry and this was also remotely sensed.

So, all this kind of complications came and it was beyond our knowledge to actually address this kind of practical problem. So, we started to collaborate with different faculty members one Professor Misra is one of them that he is taking care of the remotely controlled sensing if you can control the sensing or if you can take the data acquisition. Some other faculty members from Electronic Department Professor Sudip Nag is working on the development because in our knowledge we could only do it, but he is expert in this field. So, he developed a printed circuit board may be in other forum we will show those kind of things whatever has been developed from this lab. So, materially is the art of this kind of activity because finally, we will have to sense selectively a gas you should know what is their concentration. And exactly, which temperature how it is varying. So, if this temperature is too high you need a separate power circuit to drive those kind of sensor so those are the issues.

So, using that feedback we are do something to reduce this temperature this part of our research. And this is a thing I feel it is enough for someone to understand that what exactly is done in this laboratory. Now, you will have to make the sensor as well I mean this is not only the material, but sensor in different forms.

So, we have the facility to deposit a thin film by flugery technique. And mostly we use it in the other lab we have done microwave assisted hydrothermal technique were we can make porous material or different types of nanostructured material to know their gas sensing properties.

Thank you so much for Professor Basu Majumder. So, we are going to have a look at other facility that we have over here where we will see how volatile organic compounds would be sensed. Yeah, that is one of in case of volatile organic component it is difficult to get the cylinders for all those things. But you can easily have your gas lighter and you can put butene gas in it you can easily have some kind of paint, where toluene is there so just we have developed a chamber may be one of our students will explain it better because she is in the way of in the processing of developing it.

So, we will just go there and see that how this evosis are being sensed in this laboratory. So, I am going to now introduce to you Miss Shamistha, who is a PhD scholar, jointly been supervised by Professor Basu Majumder and by myself. So, Shamistha could you please explain the setup that you have for sensing volatile organic compounds like; methanol, butanol etcetera.

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Yes actually the gas sensing setup is broadly classified into two types one is dynamics and statics. Dynamic system is already explained to you by sir. And this is a static chamber through this one we are introducing the gas through this hole. And there is a sensor array data can be taken through this we can take multiple sensor data from those probes that are there we will keep an area of sensors. And we can take data and this is a real times gas sensing system because it is exposed to real time environment.

Here the conditions are isothermal, but here as it is exposed to environment. So, this is basically a miniature miniaturized version of gas sensing system. This is a gas sensing probe, where you can see, we have, this is heater this nichrome wires, you can see with in a mica, mica sheets that is separates provides insulation between that heater and the sensor. This is sensor and this is the NTC that is an negative temperature coefficient material it is a NTC thermistor actually used for sensing for it is for used as a temperature sensor and mostly it also abstract the in-rush flow of current to the sensor.

And then you can see this is a temperature controller, here PID control unit is used, we have designed a PID controlled circuit here. And then through this NTC which I said as a temperature of that resistance of that material is increasing, the resistance is decreasing.

So, that is some way acting as a feedback to the system. So, depending on that the power that is the power transistor, which is there the input to that is varying. And depending on that we are able to control the temperature at particular at a particular point at which we will perform a experiment.

So, now you can see this is the base line the for this sensor first of all this is a sensor, this is fabricated on a glass, the base material is a glass. And then using soil gel technique we have using a spin coating unit we have developed a thin film of copper oxide, this is a p-type MOS, sorry, metal oxide semiconductor sensor. So, I will show you how is it working.

First of all, when at a particular optimum temperature this probe is exposed to the environment the oxygen reacts with the surface of this sensor. So, there is some chemical absorption process taking place on this surface, due to which we are getting the electrons this is a p-type material. So, the minority electrons that are there, those are taken up by the oxygen which have higher affinity towards the electron. So, what is happening the conductivity of the p-type material is increasing.

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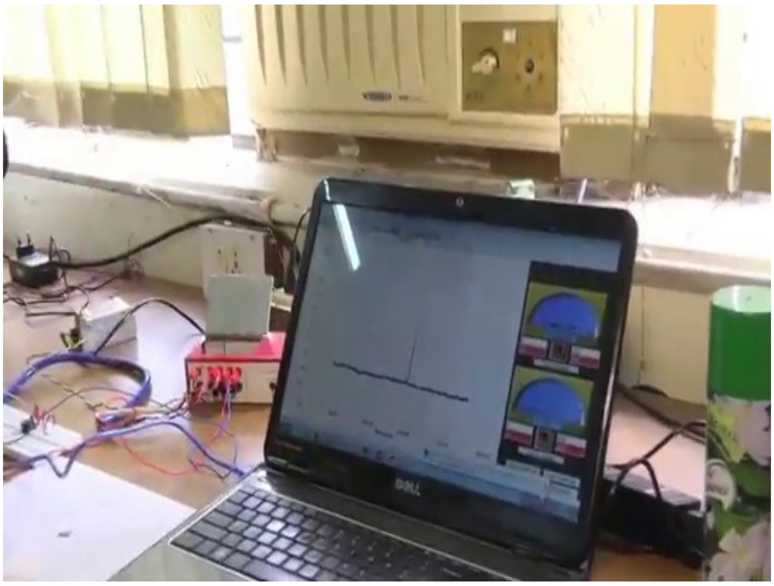


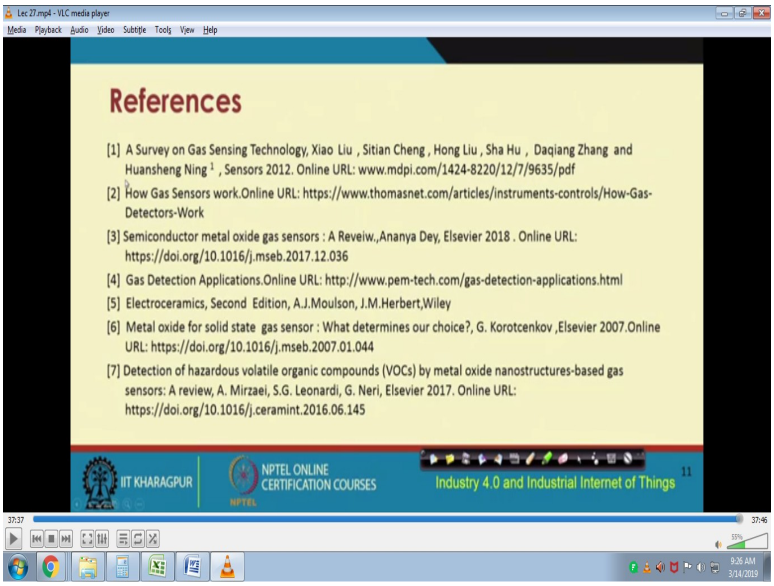
So, we can see whatever the voltage label we are getting here it will be the highest voltage. After a introduce we will see this is having some ethanol this freshener actually has some ethanol content, which is a VOC, so this particular sensor will detect this VOC. So, let us see so you can see the response there it is falling there the voltage is falling it is able to detect that there is a volatile organic compound there in the environment depending.

So, thank you Shamistha, so Shamistha could you tell us now about the different applications of these kind of sensors.

Yes these kind of sensors are widely used in different kind of industries. For example, if you go for oil and gas industry the workers working there are exposed to different harmful gases. There the diesel engines that are used to run the machineries, there in the oil factory those emits such radiation the exerts that are emitted contents very harmful gases like hydrogen sulphides, nitrogen oxides, all those things. And some particular metals those are very much harmful for humans it may cause lungs cancer, respiratory diseases.

Ok.

And also while in bacteria fabrication there you may be exposed to emissions of carbon monoxide and carbon dioxide at those place monitoring the concentration of these gases are very much important. So, there are even more wide scale are used in different kind of industries of these gas senses. Thank you Shamistha. Thank you, Professor Basu Majumder.



So, these are the references finally. And if you are interested about the designs of any of these types of metal oxide gas sensor this is the one that you could go through. And there are many other references as well. So, depending on your interest you can go through any of these references.

Thank you.