Sensors and Actuators
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Lecture - 48
Microscopic Inspection of Diced wafers and CNT Sensing Layer for fabricated sensor

Hi, welcome to this particular lab module. In this lab class, the idea is to show you how to dice the wafer. What I mean by that? You now understand that we use entire silicon wafer, right. And once you have the silicon wafer with many sensors, you have to chop up the sensors.

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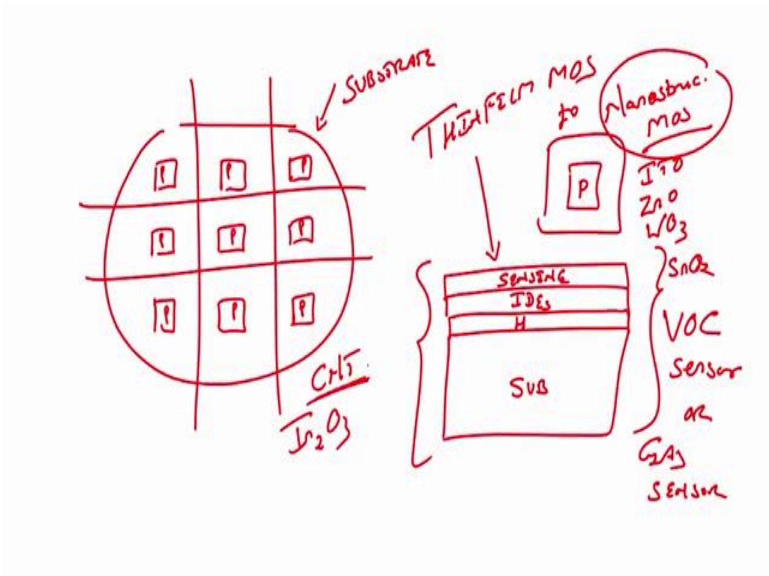

So, if you see the screen if you have silicon wafer and then you have let us say 3 by 3, 3 rows, 3 columns sensor chips right and finally, the sensor chip may be like let us say pressure sensors, ok. Now, this is our substrate, I cannot use the entire substrate for measuring something right I want to dice this off, that means, I just want a pressure sensor to be out. So, how to dice it right? So, we can dice it like this, then we can get a pressure sensor chip like this. So, how our diced wafer under the microscope looks like, we will see the inspection of that; also we will look at the CNT sensing layer for fabricated sensor what does it mean.

Let us say I will just show you in terms of blocks. So, you have a substrate again right. And on the substrate, you have a heater; on the heater you have inter digitated electrodes; on inter digitated electrodes you have a sensing layer. Now, what does this become, this becomes a voc sensor or gas sensor right. You have a substrate, a heater, inter digitated electrodes and sensing layer.

Now, you know that if I change the sensing layer from thin films of metal oxide semi conductors to nano structured metal oxide semi conducting materials like indium tin oxide, zinc oxide, tungsten oxide, tin oxide right, indium oxide and many more.

Then the nano structure also, I can use CNT right carbon nano tubes. The nano structure would show a higher sensitivity at a lowered room temperature because it has a higher surface to volume ratio compared to thin films, and that is why we go for a sensing layer which is made up of nano structure materials. So, we will see in this lab that how the carbon nano tube looks like on the wafer which has those sensing layer and so CNT is a sensing layer on the wafer which has the inter digitated electrodes alright

So, this is a lab class and I will request my lab assistant actually he is a project assistant, I am sorry teaching assistant Anil is also a part of this particular project. Anil to show it to you how this chip looks under the microscope, right. And I will see you in the next class, till then you take care, bye.

Welcome to this module. As part of the last few modules we are looking at sensors several examples of sensors that we have fabricated in our facility. And I have shown you like how a glass wafer will be, how a silicon wafer will be, how it will look like after it is deposited with gold and what are the processes that is involved in making micro heaters, I have shown you all those things.

Today, what we will do is, I had we had a glass wafer that was deposited with gold, ok. And I have shown it to you in the previous video also. I will show it to you today as well.

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And I will show you after patterning how the glass wafer will look like. And this electrode which I am showing I think you might have seen previously in the course, but I think you might not have seen before and after pictures of the electrodes on the glass wafer. Now, the idea is that I have told you that we are using these sensors for biological applications, right.

So, you need to also understand that what is the relevance of several designs in the context of biology, like why do we decide to make micro heaters in such specific way, why do we decide to place micro heaters in specific way, what are the design challenges and all. Many part of this I have covered in the previous module, I will further extend that knowledge in this module as well.

So, I have told you that main process that we that are involved will be a photolithography the pattern before that we will do deposition. Some form of deposition either EBeam evaporation or sputter deposition or thermal evaporation, and then we will after deposition we will pattern it, and then we will etch out the unwanted material from the wafer.

The wafer or the substrate may be silicon, glass or it can be instead of silicon wafer it can be a germanium wafer, it can be a PMMA substrate, it can be glass substrate lot of different varieties of substrates are available. Now, let us, I will show you a few of the patterned electrodes on glass.

Here I have two wafers; one is a glass wafer which I have shown you in previous modules which is blank deposited with gold, and another one we have patterned with electrode structure, ok. Now, I will show you the electrode structure also under the microscope again, so that it becomes very clear to you. The thing is I am not opening it directly, you should always carry your devices or wafers in wafer carriers for contamination purposes and also for safety of the wafer. So, it does not break. These are all expensive materials and it should not break. So, it should be carried in wafer carriers also in all the time.

So, let me open it for you. So, I am opening it and this is the wafer which is deposited with gold, I think you can see it. Now, I we have put this protection layer of plastic on top of the glass wafer, so that when you close the lid of the wafer carrier nothing happens.

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So, here I have taken it out; now, this is the glass wafer which is deposited with gold. So, we have the wafer deposited with gold in the wafer carrier, you can handle it with the tweezer. And if at all you are handling with your hand make sure that you do not touch the active area of the wafer. So, if I am handling with my hand like this should always be handled like this and do not touch anywhere inside the wafer because that will leave your fingerprint mark on the wafer. Now, this is a glass wafer that is deposited with gold, there is no patterning done on this ok.

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Now, I have; I will show you a patterned glass wafer. So, this is patterned. We can see it right the gold has been removed from areas, where the gold was not required. And wherever the device is there, it is there. Now, if you see if you observe, this is a 4 inch glass wafer, ok. Now, the active that these patterns that you are seeing are the devices, ok and the devices are there are lot of area where around the device which is where gold is still there. Why has this happened, this is because we have you so this is something to do with photolithography, ok.

So, for photolithography, we need a substrate as you will know with deposited with some material. You will coat that substrate with the photoresist and you need a mask with the pattern design on it, and that pattern will be transferred onto the substrate correct. Now, if usually for 4 inch substrate, you will need to use a 4 inch mask; likewise you can even use a 5 inch mass with 4 inch area in the mask, but we have used a 3 inch mask because we make these designs also on 3 inch glass slides.

So, on a 4 inch wafer with deposited with gold we have used a 3 inch mask to pattern this, that is why many of because 3 inch mask will only be this much area. So, the remaining portion of the gold will not be patterned, because it is not that mask is not covering that area, that is why most of this area of is gold and this is the active area and we can see that devices here. So, we will quickly see these devices under the microscope.

So, we have; I have a microscope behind me, I will quickly load this micro device onto the microscope ok. Just see me I will be loading it. Already some devices are there on the microscope, I will first remove those devices keep it somewhere else, and then load this chip. So, this is how you should handle your devices. I have one device in my tweezer, this is something else I will talk to you about this also. I will remove whatever is already loaded and then keep this electrode. So, I have removed it. Now, I am transferring the patterned gold electrodes onto the microscope.

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Now, you can see that I have loaded the device on to the microscope, this is the methodological microscope you have covered this in the course before. Now, let us look at the, let us start the software to see the image. Let us look at the computer screen.

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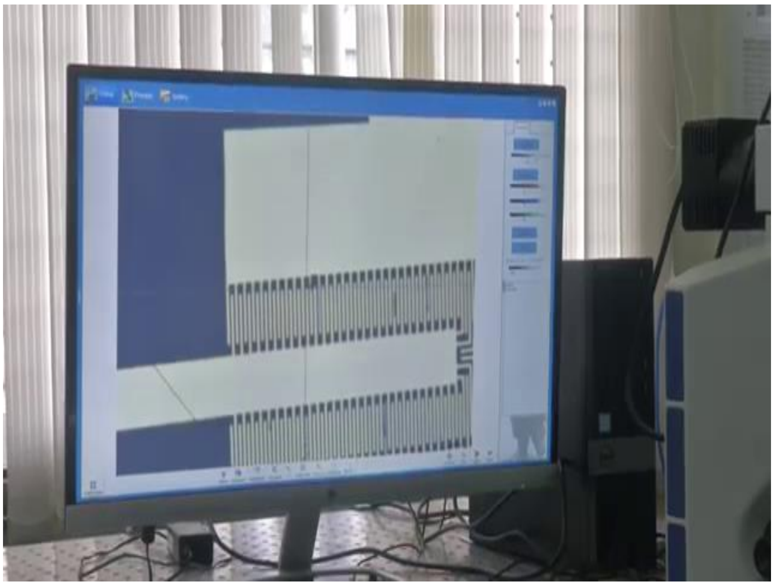

So, now I am opening the software. I have to adjust the white balance and the auto exposure, so that we can see this thing and then I have to go to the right kind of magnification that I need. So, what magnification will be used for imaging that depends on your understanding of your design, ok. So, this design is a 10 micron, 20 micron features. So, I can see the overall structure of the design, if I go at 5 x lens that is 5 x lens with 10 x eyepiece magnification that will be 50 x magnification.

So, let us look at it now. So, I you can see the computer screen. So, I am going to find out the exact active area of the device. So, it is come you can see it. I will go to another device. So, you can see the entire device under the microscope now. So, you can see major electrodes here, major electrodes there and you can see fine structures here, those are the inter digitated electrodes; inter digitated, digits like fingers. So, fingers are also called digits on your limb, this is called a index finger. So, they are called digits also.

So, these are like fingers, they are 10 micron with and 10 micron spacing gold electrodes ok. So, these can act as sensing layers for a multiple purposes whatever. So, because by default if nothing is there on; if nothing is there on top of this, this will be a infinite impedance right ideally. So, if something some material some analyte is kept on top of this electrode, it would cause an electrical connection that through that electrical connection we will be able to measure the resistivity of the electrode. So, for different biological material, we will have different resistivity. And with the same biological material of different conditions of it also, there will be different resistivity. This can be used as biomarker for detection, there is how these sides are this type of bio sensor works.

So, this is the electrode that we have seen in the glass wafer, ok. Let me just go to higher magnification, just keep looking at the screen. I will go to let us say 10 x magnification. You can see that their focus has shifted because every time we are changing the objective lens, we have to focus it. Now, it is in focus you can see the inter digitated structure more clearly now very clearly, correct. You can see it very clearly.

Now, let me go to another higher magnification, let me go to 20 x. This is 20x, I will do further focusing. So, at 20x you can see much more clearly the features of the digits, how rectangular are they; are they perfectly rectangular they will not be perfectly rectangular, because if this electrodes are made using etching process. So, it is slightly at the edges there will be some curve edges. These curve edges will be very clearly visible. We have gone to 20 x magnification.

Now, you can see the digits of the electrode much more clearly and you can see the features of the electrodes how fine are they, the curvature of the electrodes and all you can see. Ideally they should be very perfectly rectangular in design, but the process that we use, we do lithography and then we etch, with etching process. So, with etching process may not give such sharp features for that only we go for dry etching.

So, this is a chemical etching process and that involves some liquids and there will be undercutting and that etching is more towards isotropic etching than anisotropic etching, because of all these factors you can see some circular features on the electrodes. This you can be very more, more clearly if you go to higher magnification. So, if I go to 50 x magnification keep looking at a screen, I have gone to 50 x magnification. And I am focusing it. So, I have focused it.

Here you can see the fine features on the electrode that you can see that it is not perfectly straight, if there are some roughness which is toleratable, because it is at very high magnification. At 50 x magnification, you are still able to see that it is reasonably straight. You can see this, this structure this curvature right, you can see a U shape here, slight U shape here, slight U shape here, these are all at high magnification you can see it. If I go to even higher magnification let us say I go to 100 x, 100 x lengths, you can see much more clearer picture. I will increase the brightness.

So, you can see how like the imperfections in the design you can see, see here means some material is gone some here metal is gone which are for our sensing purposes. So, I can go to the other structure also that U shaped structure. See the U shape you can see, it is supposed to be perfectly rectangular you can see the edges are actually curved with this is because of the isotropic nature of the etching process that we do which is fine for our sensing application.

So, you can see that at 5 x magnification, it looks a bit more perfect manner than when we go to this is basically sensor inspection. You are inspecting how your etching profile has been how your design has finally, and how other design that you have made in the mask, how it has been transferred to the substrate. So that is how you do inspection by going to higher and higher magnifications, ok.

So, next we will do, we will see one sensor that we have made on silicon wafer. Previously we saw gold patterning on glass substrate; we saw a glass substrate that was blank deposited with gold. Then we saw a patterned glass substrate with the gold electrodes. We saw it under the microscope, we saw how the features are visible as we go at higher magnifications, ok.

Now, I will show you another design which we have made on a silicon wafer. On the silicon wafer, we have deposited platinum and we have used lift off process to make the features. Why we have used lift off process, so generally people go for lift off process when there are no clear very practically usable etchants available for the deposited material.

Let us say when you have; then you take gold, you have good etchants which give you a controllable etch rates in a wet bench. So, you can use direct etching process. But platinum some people use aqua region and all, but that etch rate is extremely high you will not be able to preserve your features. So, for that people use lift off process, I think lift off process has been covered in the lecture course before; I will not go into details of it.

The basic idea is that before you deposit the material that is platinum itself you do lithography. After coating photoresist onto your substrate, you do lithography pattern transfer onto your substrate. And then on the patterned substrate you transfer your; you deposit your material in this case platinum and then you do the lift off process. The idea is the photoresist will come out by and while it comes out it will take away the material platinum from places where it is not required. There is the overall idea of lift off.

An analogy is like let us say you have put some things on a bed sheet and you want to remove that item you pulled a bed sheet and the item comes with the bed sheet. So, it is something like that, just that it is not exactly a bed sheet because if it is a bed sheet is in a blanket removal. So, if you just simply remove the PR, whole platinum layer on top of will come out. But because you are developing the PR some part of it can be taken out and some part still remain and the platinum can be preserved with the features.

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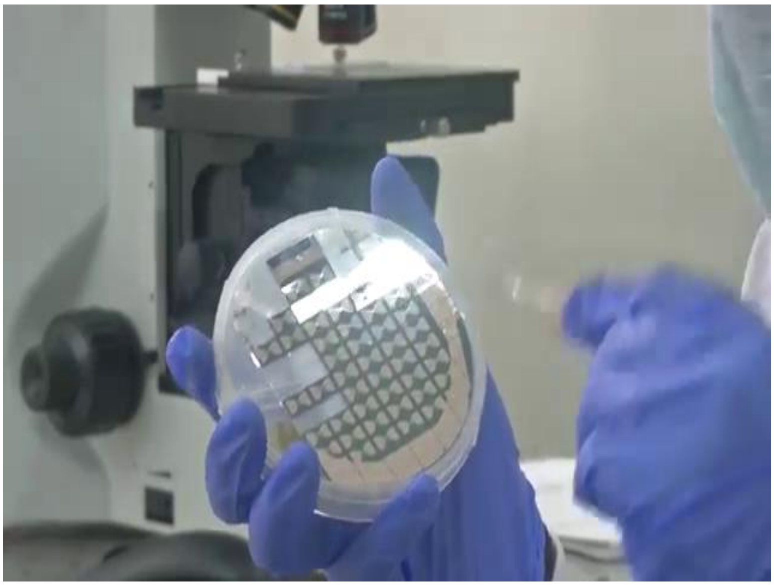

Now, we have I will show you the substrate that has been patterned through liftoff technique and diced as well. So, diced using wafer dicing machine, so that way because you will not be seeing the devices in a full silicon wafer, but it is a diced silicon wafer. So, you can see it under microscope so under the camera. So, this is this is part of a whole silicon wafer ok, but what we did these are individual chips you can see, we have diced this wafer.

And with dicing is done using an automatic dicing machine that is available in the institute. And we give the pitch and spacing of the device of the devices and that machine will go around making x and y lines on your wafer. It is a very sharp tip like dicer. And we will make these lines on the wafer. And the devices will come out you can see this dice dicing lines on the wafer.

Now, this is a special design, where that incorporates micro heaters, temperature resistance temperature devices electrodes, isolation trenches a lot of things on this device. I will not going to the application of it because it is still under research, but I can show you the design as such. And before dicing we keep the wafer on a sticky paper, so that it can be diced by the machine that is why I can take it like this. The devices are on it, and the devices you can see you can take it out from this sticky paper sticky material. And the material will be diced and we can take it out.

Now, I have removed. So, this is the wafer with the platinum electrodes and the devices have been diced.

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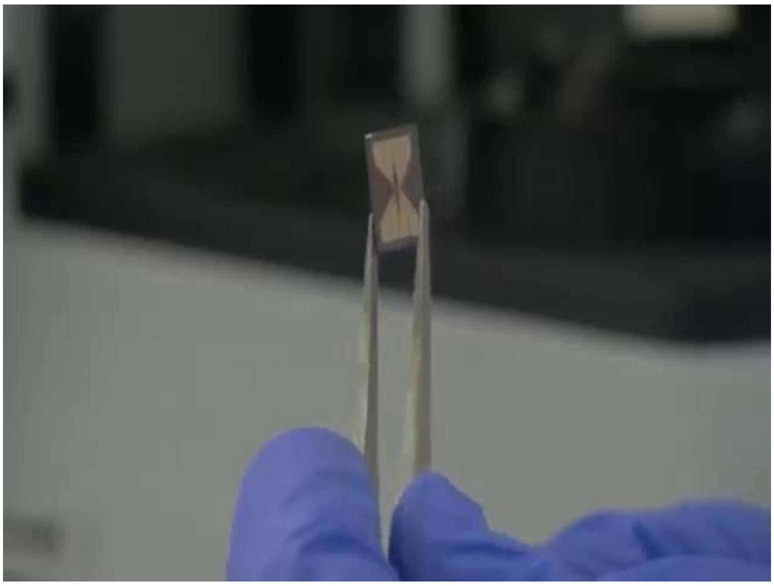

Now, from this wafer I have taken out one device, so that one device is in my tweezer here. You can see it in this, this is one device. We can see this device under the microscope then I will explain to you what is it about. So, we have seen the sensors on the substrate, right. Now, I have taken one such sensor and I am holding it with my tweezer here. You can see it right in my hand this is the size of one sensor, ok. Now, let us look at the sensor under the microscope. So, I am keeping it under the microscope. You can see the microscope behind next to me. I am keeping it another microscope; we will look at it under 5 x optical magnification, ok.

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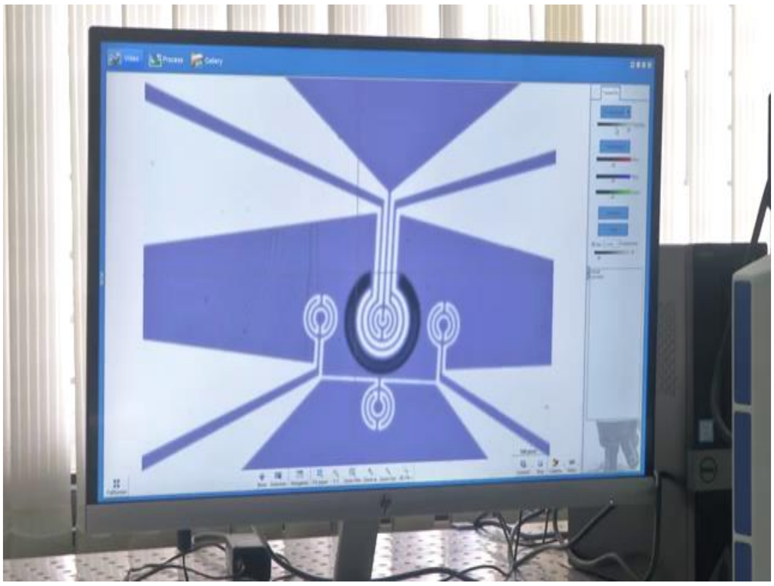

So, let us look at the screen, I will focus it, now let us see the sensor. So, you can see the sensor now on the screen very clearly, correct. Now, if you see the major part 80 to 90 of the sensor are contact pads, the active area of the sensor is very very small, it is only 0.5 mm by 1 mm ok, which is what you are seeing in the screen. At the center you can see a circular structure which is a micro heater. Around that micro heater you can see inter digitated electrodes in a circular fashion. Around that you can see a dark ring like structure, correct. The dark ring like structure is actually a trench or a deep hole that has been made for thermal isolation.

Around this trench, you can see 3 structures right, 3 winding structures these 3 winding structures are again resistance temperature devices. What are resistance temperature devices, resistance temperature devices are also like micro heaters, but the thing the difference is that they are not actively heated, that means, they only respond to a change in temperature to which they are exposed too, they are themselves not heated to a particular temperature.

So, resistance temperature devices change their resistance as heat is impeached on them that is the idea. The, so the idea is that you heat the micro heater to a particular temperature, you put a sample on top of the sensor and that through the micro heater that temperature will spread right, and that change in spread through the sample will be dictated by RTDS that is a general idea about the working of the sensor. And there are a lot of applications which we are not allowed to diverge. So, this is how you make a sensor design.

So, you can see that this the sensor has a electrical properties, thermal properties, lot of properties also included in the design which can be measured ok. So, this is one design. You can see the bigger metal parts that are going out are actually for the contacts for the pads. They eventually end up with pads we can I can show you the pads also.

If I go towards the right, it keeps going. You can see that these that width will keep on increasing and it will end up in pads, these are pads. This is the edge of the pad, ok and the dark edge that rough edge is the edge of the sensor. This white thing is the pad, pad of each of the connections. And what you saw at the center is the active area; it is called the active area of the sensor. So, you have seen how the sensor structure is how.

So, let us come back. So, you have seen how the sensor structure is. So, we have seen how silicon wafer which is find a micrometer in thickness can be diced, how platinum material can be deposited on top of the sensor, and how it will be diced. And what is a process that you use if you have a material for which you do not have an etching etchant proper etchant which can give you controllable etch rates, what is the alternate process that you can go for which is lift off that we have seen.

We have shown you how we have made a sensor with platinum using lift off technique, how the process was done; how that wafer was diced using an automatic dicing machine we did not we do not have that machine in our premises. So, we just spoke to you about that, then how it will be stuck on to a sticky material and then you can you saw the dicing lines on the substrate. Then I took out one such wafer one such sensor, I showed you that sensor in my tweezer, and we looked at it under the microscope also, and saw how the functionally it might be useful for any sensing applications, ok.

Now, another example that we have is you might have seen the sensor during this course of this project, course of this NPTEL course it is a small, it is a very simple micro heater structure that we have. I have here with me a lot of micro heaters on this wafer I have a lot of micro heaters on this wafer, ok. One such micro heater let me take it in my tweezer, it is very small micro heater, it is literally in the micro. So, I have it in my tweezer. I do not think, I do not know if you can see it, this is the size of the micro heater ok. And there, at the top and bottom, you have contact pads for the micro heater, and it is a winding structure.

Now, how do you handle such things to make intelligent systems? So, for that how do you handle such things to make intelligent systems? So, for that you need to use a technique called wire bonding ok. So, you can increase the area that you have to work with by bonding these contacts of the sensors on to a PCB kind of structure using a technique called wire bonding and then you can take the contact pads from there. I will show you this same sensor that has been wire bonded onto a substrate.

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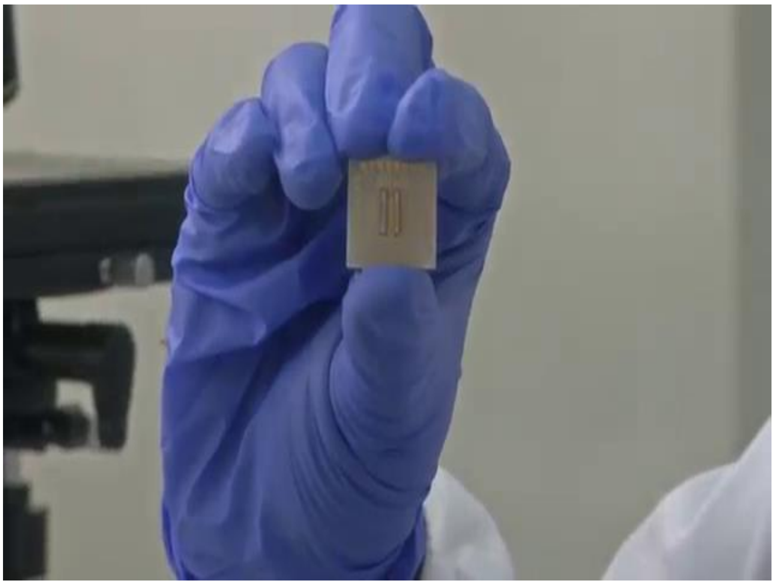

So, in my hand let us look at it in close. In my hand, I have the sensors which you can see and their contacts have been wire bonded on to these pads and these pads can be taken from here. So, now, it is very easy to solder onto it this is like a PCB this is a PCB only from the sensor we have wire bonded onto the PCB and we can take out from the PCB. See this is part of packaging, it is called MEMS packaging.

So, we have packaged in the sensor in a way that it can be used into another further or upstream or downstream electronic circuit, otherwise it is very difficult. If you do not package, it will be difficult to interface it with a downstream and upstream electronic circuits. So, that is the importance of packaging, so that is how the small sensor we have made it in a size that is hand level in our hand and we can interface with a bigger electronic circuits that we might be having. So, this is one system on one of the methods that are used for MEMS device to make systems out of it. So, packaging is a very important aspect of that, so that is what we saw now.

Now, another sensor that we can have is again electrodes, but the size and dimensions are different, just wait a second, let me close this up and then we can see the next sensor. Now, it is a similar structure as compared to what we saw for the platinum electrodes. These electrodes are also platinum based, but these are used for gas sensing applications.

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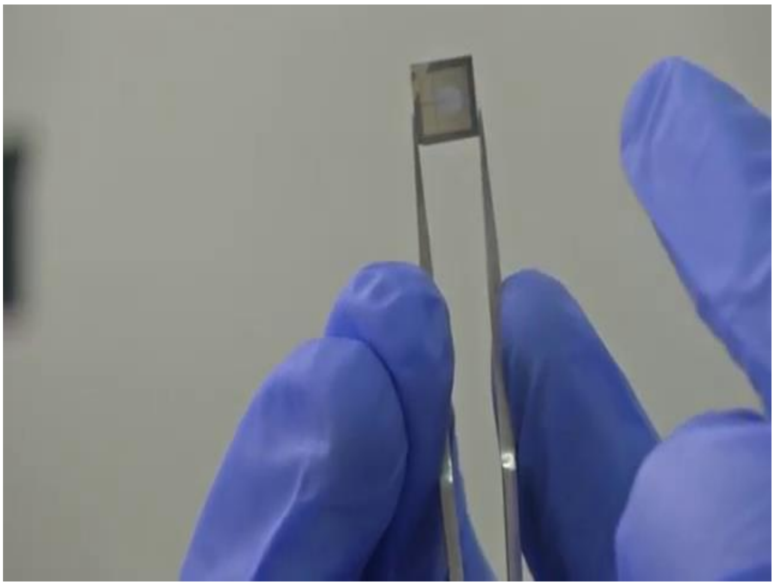

You can see the sensor in my hand here. You can see a bright spot a white color spot at the center right that is because it has been coated with an active material for sensing applications, and underneath this active material you have electrodes.

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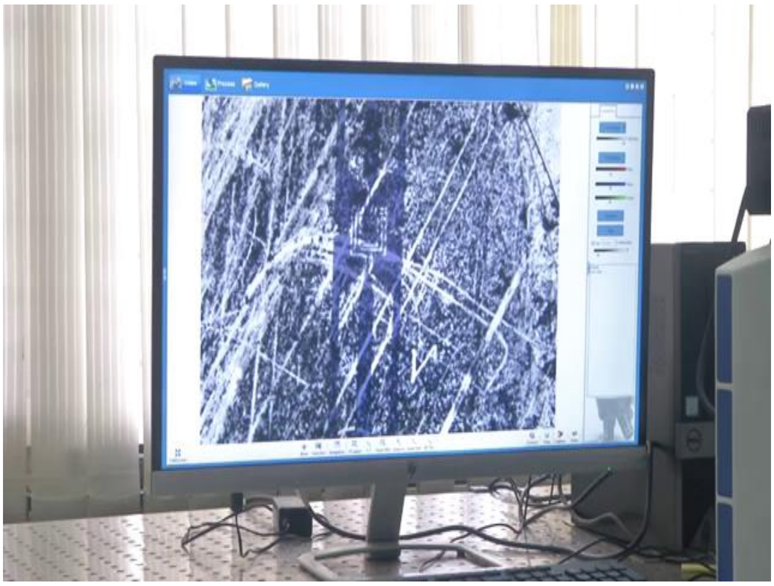

So, let us look at this also under the microscope, I have kept it in a microscope. So, this is an electrode on top of which we have a sensing a layer, ok. So, let us look at this computer screen. So, you can see the computer screen, it is very difficult to see you can just see it. So, you can see the mouse pointer on the screen. So, you can see the mouse pointer. So, you can see that underneath, there is a lot of noise right lot of it, it looks like some dirty thing, but it is not actually dirty, it is the sensing material which is carbon nano tubes.

So, if you have to see these carbon nano tubes properly you have to go for SEM imaging, not optical imaging, but underneath this nanotube you can see this electrode structure here below, you can if you look closely you can see the electrode structure. So, on top of the electrode here; on top of the electrodes we have coated with carbon nanotubes. So, this will act as a sensing layer. So, if some material comes and interacts with the carbon nanotubes, it will change the impedance of the underlying electrode and that can be used for sensing.

So, this is a course in sensors and actuators that is why I am making you through different, different interesting types of sensors and how they can be actuated in the real life real world situations. So, this is one type of a sensor that can be used ok. So, in the past several modules short modules we have seen different types of sensors, different types of materials, different types of processes, different types of substrates, gold glass substrate, silicon substrate gold material, platinum material, etching process, lithography process, lift off process, a lot of things we have seen sensing materials carbon nanotubes I have introduced you to all these things.

Now, as to the next step what we will do is we will see these actually these sensors I have to talk to real world systems, right. So, how do you, so let us say if I take a sensor that can measure properties of a material how do you prepare the material, so that it can measure from the sensor. So, one such material that we use are tissues from patients. So, how can we; how do we prepare the tissues, so that it can be used to measure with the sensor.

So, in the next module we will look at how issues can be deparodo parasitization is a process which I will introduce to you in the next module, and we will see how tissues can be prepared. After they have been taken from the patient hence preserved for a long term preservation from such samples from long term preserved samples, how can you take out tissues and how can you process them and condition them, so that they can be used for measurement with the sensor, so that will be next module. Hope you are finding all these modules interesting.

Thank you, see you next time.