Fabrication Techniques for Mems-based Sensors: Clinical Perspective
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Lecture – 13
Micromachining: Fabrication of VOC Sensor contd.

Hi. Welcome to this particular module and in last module what we have seen we have seen bulk micromachining and surface micromachining. And then we have taken an example of using a bulk micromachining how to create or how to design a process flow for fabricating a sensor for detecting volatile organic compound right. So, in detailed we have understood how each step can be formulated right to fabricate this particular device right. And as you see there are multiple mask that we to use at fabricate such a device.

Now what if I say that we need to still reduce the temperature; know you right that what we will discuss the last module is we have to use integrated heater to heat up the sensing material correct. Now, this heater to reduce the power consumption to achieve a certain temperature, we are fabricating a diaphragm. Now when we fabricate diaphragm instead of a heating the entire silicon vapor, we have to heat only the diaphragm. Thus the power consumption would reduce, but I would say that I still want less power consumption. I still want to have power consumption even less then what we can achieve through diaphragm, in that case we need to use bulk plus surface micromachining right.

So, how does bulk plus surface micromachining work? And can we design a similar shot of sensor using bulk and bulk plus surface micromachining right? So, today we will see that particular part and then we will see how about not to create diaphragm. Because see there is some disadvantage when you create diaphragm; yes, you reduce the thickness vapor the mechanical stability of the vapor also reduces.

So, the sensor mechanical stability reduces, but what if I say that we can have the same mechanical stability. That means, the thickness silicon vapor and the thickness of sensor sense the senses that we have fabricated on the silicon substrate the thickness is same ok. Thickness of silicon vapor and the thickness of this particular device that is made using our technology that we will discuss, the thickness is same. That means, mechanical stability is almost similar, but because of a slight change in the sensor technology, the power goes extremely low and we can achieve a similar power consumption which we can achieve with a diaphragm. That means, mechanical stability is high, power consumption is low and still everything works perfectly.

So, we will look at that kind of idea and a technology. So let us see today; let us start our module by looking at bulk plus surface micromachining right.

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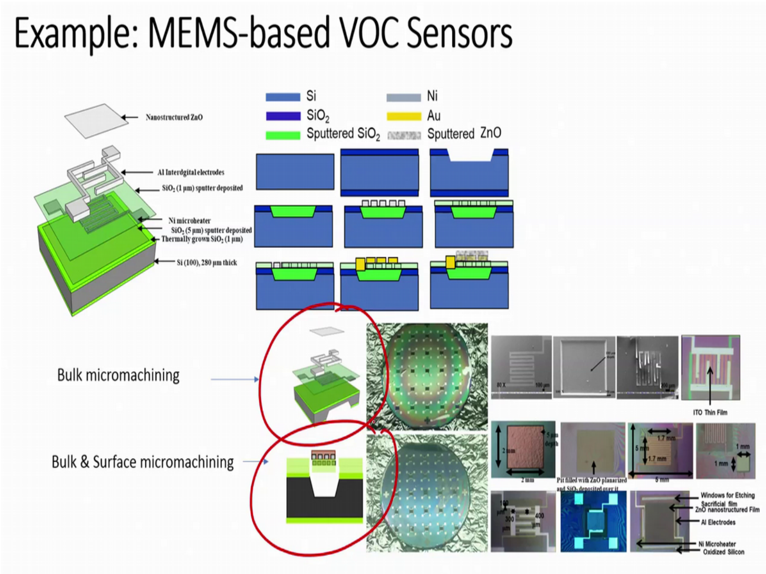

So, yesterday what we had discussed? Yesterday we discuss this particular sensor right. Today we will discuss this particular sensor. So, what is exactly the sensor is?

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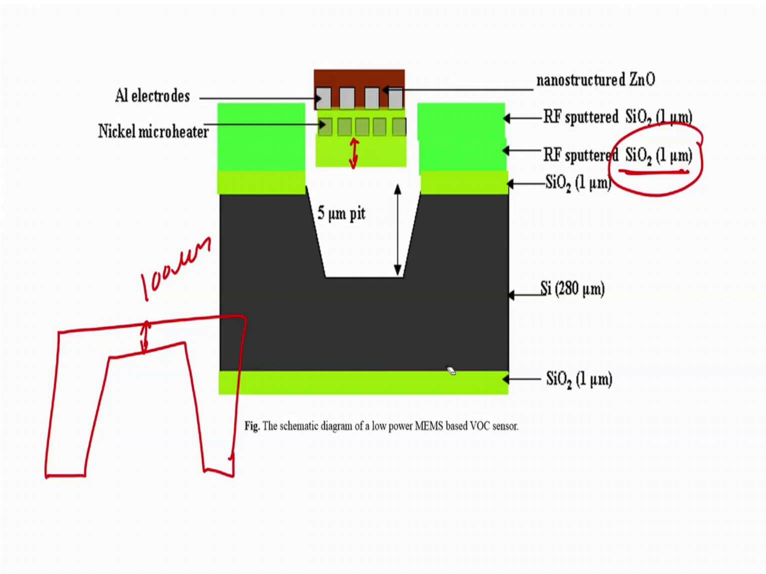

Fig. The schematic diagram of a low power MEMS based VOC sensor.

I can see here. This is a hanging structure; is a hanging structure is a cross sectional image that is why you may not be able to see the hinges. But it is a hanging structure and the thickness of the bridge on which it is hanging right is just 1 micron, only 1 micron thick right. So, from diaphragm that we have seen yesterday which was about 100 microns we are now talking about 1 micron

So, when we talk about 1 micron right, the power consumption would be even less power consumption would be less. So, what else this sensor consist of? Sensor consists of a heater which we have seen yesterday. Then there is a sputtered silicon dioxide you can see here right and then we have inter digitated electors made up of aluminum. Finally, we have a sensing layer made up of nanostructure zinc oxide material. We will see if you SCM images of nanostructure material how it looks like right. And this pit is created using bulk micromachining; 5 micron pit is created using bulk micromachining. This is released with help of surface micromachining right.

So, you will see where bulk micromachining comes into picture where surface micromachining comes into picture. And we have given this title schematic diagram of a low power of MEMs based VOC sensor low power. Because it will have the heater will require less power to heat this, this material this much thickness of the sensing material including the heater and the substrate right and of course, your ids

So, how can we fabricate this device? Alright, let us see. Now this if you see here, we have written 280 microns, why not 500 microns, because we are talking about a silicon vapor which is 2 inch in diameter. We are talking about silicon vapor which is 2 inch in diameter instead of 4 inch diameter vapor.

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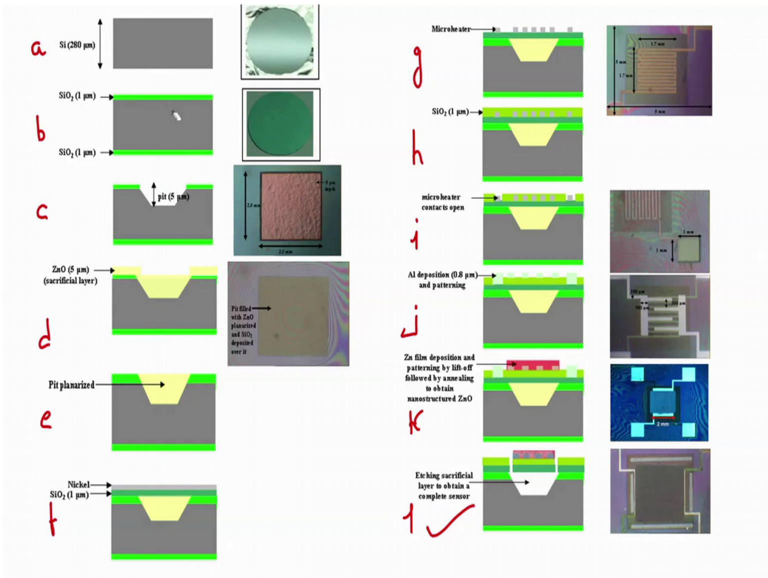

So, this is the process flow and we will see how to draw the process a design of this particular process flow or how to design this process flow in the following slides. Right now, let us understand how we can get this particular sensor from a starting vapor which is our silicon substrate right. As I said it is a 2 in silicon vapor. So, we have to in silicon vapor on which we are growing silicon dioxide right. How we are going silicon dioxide using wet oxidation? So now, can see this is a silicon vapor kind of grays in color right after growing silicon dioxide, we can see green color right.

Now, using photolithography we are creating a pit, we are creating a pit right. So, let us first understand how we are creating this pit from oxidize silicon substrate. So, if I just write down in terms of some numbers or some alphabets a b c d e f g h i j k and l. So, what we are looking at? How to create c from b? How to create c from b?

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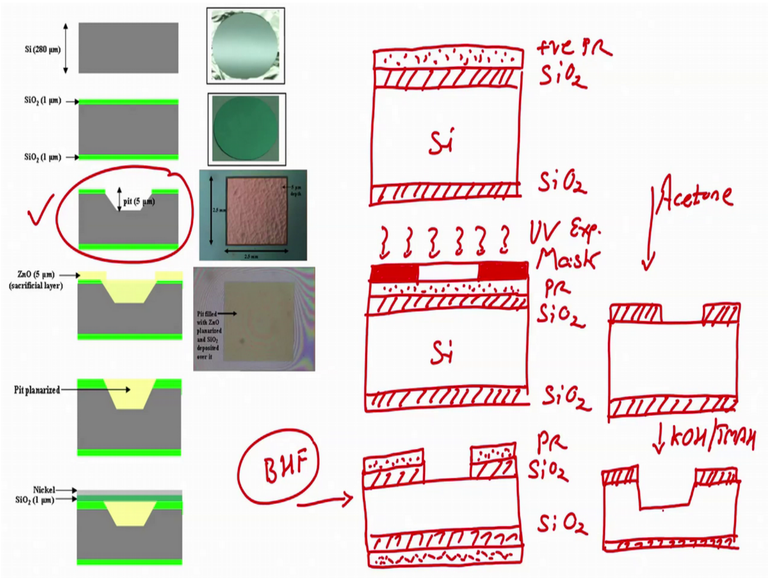

Now, you guys are expert right in photolithography right. So, you draw process flow quickly, is not it? We have oxidized silicon substrate right; we have oxidize silicon substrate SiO 2: SiO 2. And this is our silicon. What we want? We want to have this pit, we want to have this pit right.

So, first thing is we will spin coat photoresist. We will spin coat positive photoresist after spin coating photoresist. What is next step? Next step is we will load the mask will load the mask so, to open a window in silicon dioxide right. So, that we can h silicone right we want to create a pit in silicon. So, for creating pit in silicon we are to etch silicon. For etching silicon, we have to remove oxide from the area right, where we want etch silicon; SiO 2 silicon, SiO 2 photoresist, mask correct. After that of course, after positive we are what we are you do soft bake right. After soft bake we load the mask allowing the mask and perform UV exposure. After UV exposure next step would be to develop the vapor right to develop the vapor.

When you develop the vapor when we say developing vapor, does not mean that we are actually developing vapor. It is called developing we are developing photo resist, but in general we are dipping this vapor in photo resist. Let us say we are developing vapor, but we are developing a photo resist. So, photo resist we have developed. Now the unexposed area will get stronger right in the case of positive photo resist. So, the unexposed area is stronger, the expose area is weaker and you can see that the positive photo resist has been developed from the area which were which was exposed which was exposed.

Now what is the next step? Next step is we have to dip this particular vapor in BHF. BHF is buffer hydrochloric acid when we dip this vapor in BHF what we will get will get will etch the will etch the silicon dioxide because it was exposed right. So, silicon dioxide will get etched and we will create a window will create a window right

Now, what is the next step? After this next would be you dip the vapor. So, you can now remove photo resist, you can now remove photo resist. So, dip the vapor in acetone when you dip the vapor in acetone when you dip the vapor in acetone, what you will have? You will have photo resist stripped off when you dip the vapor in acetone a photo resist will strip off right. Then again the question would be when you dip the vapor in BHF with the backside will get etched or not right. SiO 2 on the backside can get etched. So, we can protect the back side by spin coating photo resist by spin coating photo resist.

So, you see here we have soft bake, then we have exposed, we have developed. After developed, we can spin coat for photo resist on the backside and then hard bake and then hard bake followed by removing the silicon dioxide through BHF followed by striping of the photo resist. Here we are with striping of the photo resist after that if you dip this vapor in KOH you etch silicon or TMAH right. KOH or TMAH and we know what is the etching rate, you know what is etching rate of KOH and TMAH, etching rate of what silicon etching rate of silicon, because this are silicon etching, then what we get? We get this particular pit correct. This particular pit or this is the process this is the process for creating a pit.

Now this is what kind of etching, the machining? We are using a bulk micromachining because we have etch the vapor about 5 microns. You can see a pit of 5 micron meters. So, we are etching the vapor about 5 microns correct. So, we are using bulk micromachining technique. Now next step d; d would be to deposit zinc oxide and fill the pit and fill the pit and then planarize it by polishing right. So, what will do is easily right.

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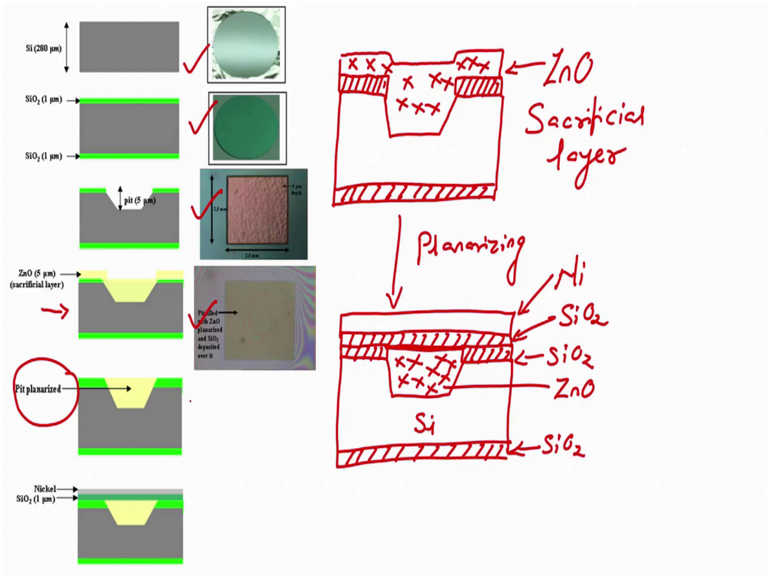

So, let us see here after this technique. So, we have oxidized silicon vapor with a pit right oxidized silicon vapor with a pit in which we are depositing zinc oxide. This zinc oxide will act as a sacrificial layer; you will see why sacrificial layer. We are depositing zinc oxide on this particular pit and then we are polishing it, planarizing it planarizing zinc oxide when we planarize it when you planarizing zinc oxide, then you get relatively smooth layer of zinc oxide right; zinc oxide. After that what is the next step? After that when you pit is planarized right pit, so, what you do? You still keep on polishing; you still keep on polishing until you have zinc oxide left only in the pit like this right.

So, now the pit is filled with zinc oxide. Let us draw zinc oxide in this particular pattern. So, we can understand that we had deposited zinc oxide. And now the pit is only consisted of now is filled with zinc oxide, because vapor is planarized after planarizing zinc oxide. The next step is we will deposit a silicon dioxide on it.

So, you understand this thing zinc oxide, silicon dioxide, silicon, silicon dioxide, silicon dioxide alright. Next is we will deposit nickel for what? Because we want to create a micro heater right; we want create a micro heater.

So, now guys go right see first is silicon, then oxidize silicon then creating a pit, then filling the pit with zinc oxide and a planarizing it and depositing silicon dioxide right. So, until this steps, we are done. So, how many steps we are done? Let us see; a b c d e and f we have just deposited nickel correct.

Now what is the next step? After depositing nickel, we have to fabricate micro heater, we have to pattern nickel to form a micro heater right. So, where should be micro heater from? Micro heater should form on the pit on the pit. So now, we have this particular substrate. From here, we need to create a micro heater.

So, let us create a micro heater. So, I will just delete this and will draw a process flow for creating a micro heater of nickel on the pit filled with zinc oxide and cover with silicon dioxide.

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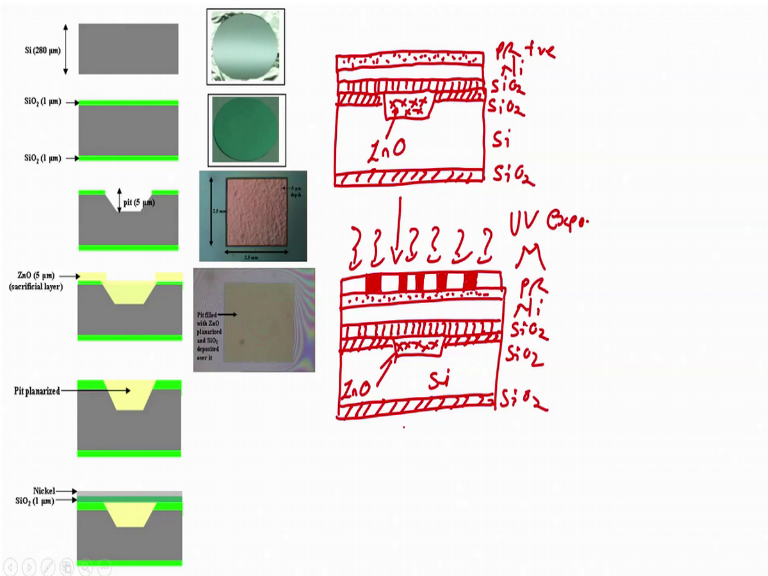

So, let us draw here. We have a pit and this filled with zinc oxide and then there is a thin layer of another oxide. Let us draw this is another oxide in this particular fashion and then we have nickel. So, nickel SiO 2, SiO 2, SiO 2, SiO 2, zinc oxide. Now what we will do? You know right you know this step very fast positive PR right. Next step soft bake next step next step is what?

Next step is load the mask right load the mask. So, you should be now faster right. You can see now I am slowly increasing the speed, because now I am sure that you guys understand what I am drawing here correct. And then we have photo resist and photo resist we have mask. And what kind of mask we have? We should have contact area outside the pit and the structure within the pit.

So, this will be our mask right, this will be our heater of course, this is what we are drawing is a cross section. These are heater pads contact pads contact pads. What we are done? So, we have mask, there we have photo resist right, we have nickel, SiO 2, SiO 2 Si SiO 2 right and here we have zinc oxide after that soft bake is already done, mask is loaded. We will UV exposure. After the UV exposure, next step would be to develop the vapor right; develop the photo resist. When you develop the photo resist, what will happen? Let us see.

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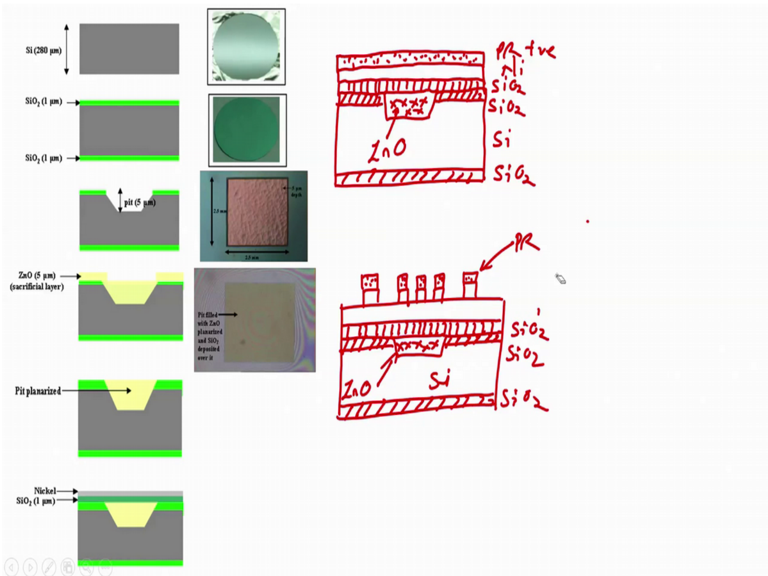

When you develop the photo resist, after u v exposure you will have right you will have photo resist left in the area which was not exposed. After that, what you will do? Next step is to etch nickel right.

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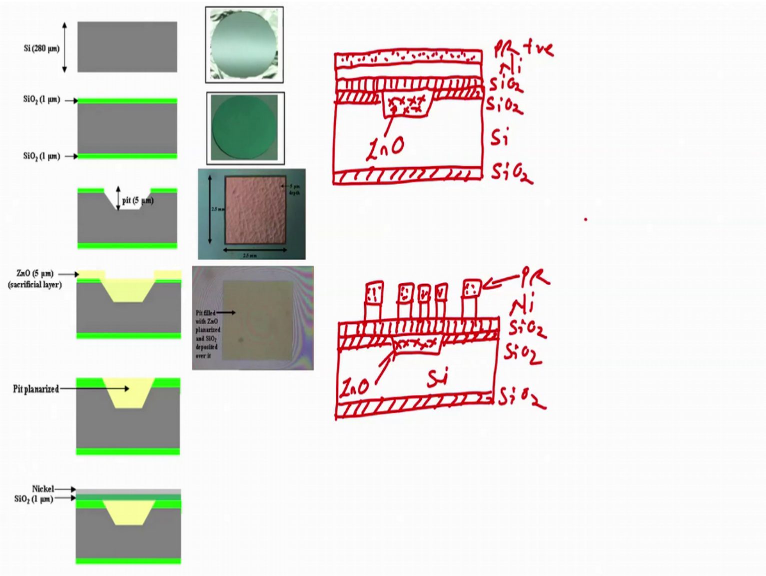

Next step is to etch nickel. So, nickel will get etch nickel will get etch in the area which is not protected by photo resist which is not protected by photo resist.

So, this is what we will have. We will have nickel which is not protected by photo resist will get etch and nickel which is protected by photo resist will stay right. After that, what is the next step? Acetone dip right, when we dip the vapor in acetone, what will happen? Photo resist will be stripped off and you will have a heater photo resist will strip off and you will have a heater right. So, where are we? We have now fabricated a heater right on the pit right. What is the next step?.

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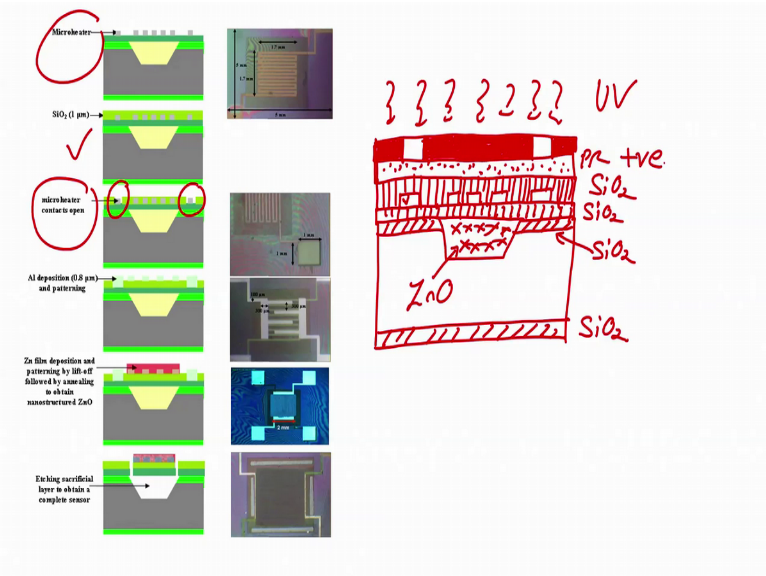

After this if you see after we have heater. Next step would be silicon dioxide right, if we have to deposit silicon dioxide.

So, let us deposit silicon dioxide on the vapor. Let me try it here is easier. This is guys bulk plus surface micromachining bulk plus surface micromachining right. And this is what we are write heater stage micro heater. Now we have to grow silicon dioxide you have to grow silicon dioxide right. Then what we have to do? We have to remove the silicon dioxide from contact wise. Why we are to grow silicon dioxide? Because next step is to form interdigitated electrodes to form interdigitated electrodes; if I let us say have interdigitated electrodes in this particular fashion right then it works.

But if I do not have this insulating layer between micro heater and interdigitated electrodes, then it will get shot right, because two metals cannot be deposited on each other or should not be deposited on each other for this kind of application. So, I am not saying it cannot be a lot of applications requires deposition of multiple materials. So, this could be my silicon dioxide right, this would be my silicon dioxide, this would be nickel, silicon dioxide, silicon dioxide, again silicon dioxide, zinc oxide; these are we are.

Now next step is to open the contact right, you can see here, you can see here. The contacts are open means that the oxide is removed from the contact window is created right; oxide is etched from the contact area. So, that we can we can you can see here very clearly if you see this square right and if you see this particular part, then you can clearly see that the oxide is there and here the oxide is not there right. If you see here the oxide is etched, how can we do that? We know it very well.

So, to do that, we will spin coat for photo resist, soft bake and load a mask such that the area which we want to expose right, the area which we want to expose or the area which we want to etched will be exposed in the area which we want to protect that is our heater area will not be exposed with u v light.

Since it is a positive photo resist the contact area, we want to we want SiO 2 to get etched right. So, we have to remove photo resist from only contact area and remaining area, we should protect the photo resist to do that we will use the mask as shown here. And then, we will expose the vapor with UV light. When you expose the vapor with u UV light, since this is a positive photo resist; since it is a photo resist, what will happen? After exposure you will develop the photo resist.

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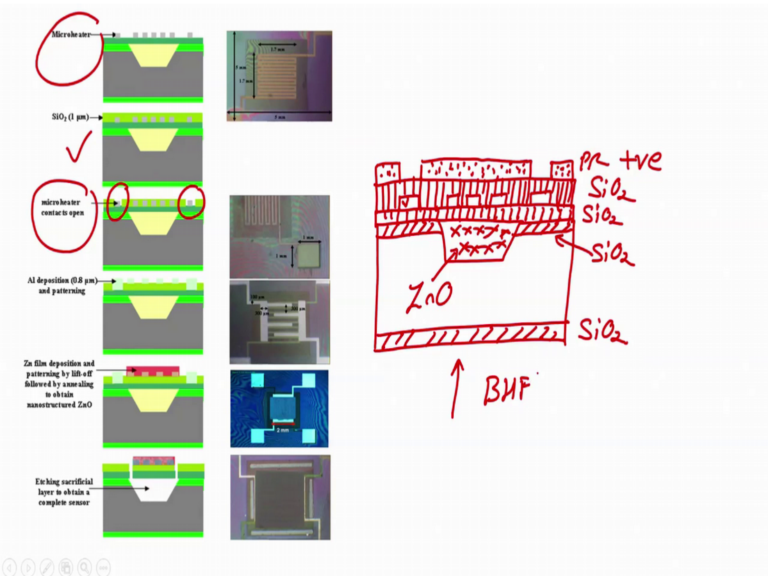

When you develop the photo resist, what you will get? You will get you get this. What you will get? You will get a positive photo resist protected in all the area except contact area. You see except contact area right.

Next step; what is next step to etch silicon dioxide? So, we will dip this vapor we will dip this vapor in BHF and we dip this vapor in BHF, what will happen? A silicon dioxide from the contact area will get etched right. The silicon dioxide from the heater contact area will be etched. Next is we are dip this vapor in, we are dip this vapor in acetone.

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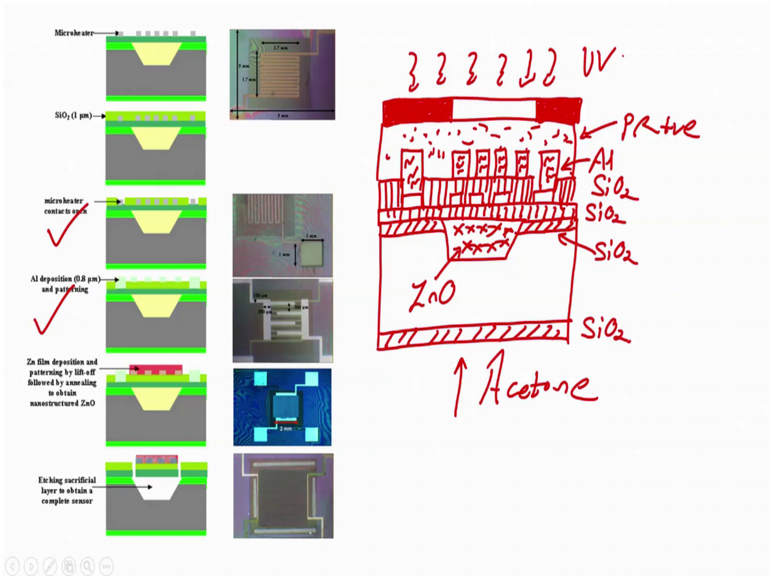

When you dip this vapor acetone, what will have? Photo resist will be stripped off right photo resist is stripped off. Photo resist is stripped off; that means, you have now micro heater contacts open; that means, silicon dioxide is etched right. So, where are we now? If you see we have we are on i, we are on i.

Next step is you see here we have to form interdigitated electrodes right. You have to form interdigitated electrodes. So, how can we form interdigital electrodes? So, let us see. Now, we have silicon dioxide. So, what will do? We will deposit aluminium using physical vapor deposition right. And let us have pattern of aluminium like this, now what do you want? We want interdigitated electrodes right. So, same step right, you see once you know it become; so, easy to use this steps right. What is this? Positive photo resist, then what you will do? You will soft bake it.

After soft baking, what is the next step? Next step would be to create interdigitated electrodes on pit right in a contact area can be outside. So, the creating interdigitated electrodes on pit we have to use a mask. What kind of mask you can use? We can use right film mask right film mask such that it has the patterns for interdigitated electrodes such that it has patterns for interdigitated electrodes right in.

So, what is this? Let me just make me sure what we are showing. This is aluminium positive air this is mask right mask, then UV exposure UV expose. So, when we expose this vapor with UV UV light, what we have? We have when we expose the vapor with UV light and then we develop this vapor. What we will have photo resist protected in the area which was not exposed by UV.

Next step would be to etch aluminium right. Next step would be to etch aluminium. How can we etch aluminium? We can etch aluminium by aluminium etchant by using aluminium etchant. When we etch aluminium then, what we have? We have photo resist the area which was protected by photo resist, aluminium will not get etch area which was not protected by photo resist, aluminium will get etched right. After that what is the next step? Next step is to dip in acetone. Where we dip the vapor in acetone? The PR will get stripped off as you can see here, the PR will get stripped off and you have your inter digitated electrodes. The PR will get stripped off and you have your interdigitated electrodes.

So, what is the next step? Next step is; now, UV are here where we have interdigitated electrodes. Next step here is to deposit zinc filled right by lift off and perform annealing. So, now, you know right how to perform lift off? We coat everywhere photo resist we coat everywhere photo resist right. Then we use a mask as mask should be such that photo resist is protected in all the area except the area where we want to deposit is sensing layer where we want to deposit sensing layer correct. So, if I use this kind of mask, this is my photo resist right, this is my positive photo resist, this is my mask. I expose the vapor with UV with UV light, I exposed the vapor right.

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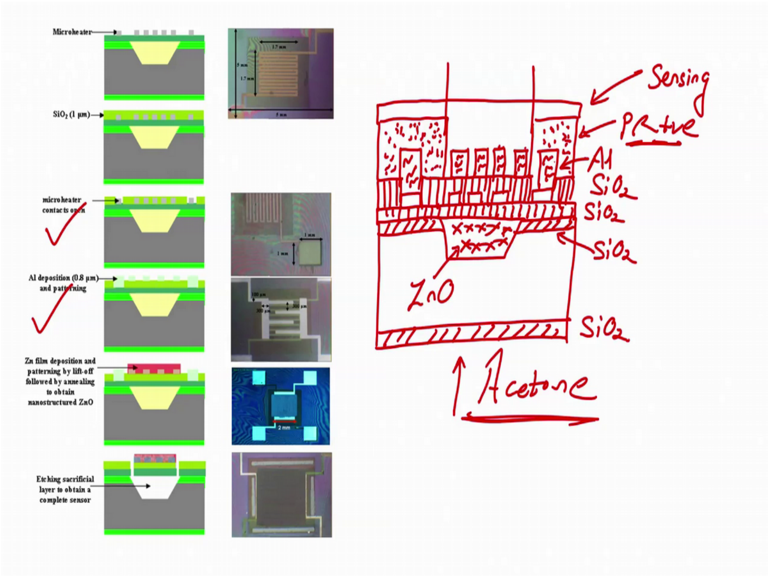

What will happen? I expose the vapor and develop the vapor, what will I have? I will have positive photo resist in this area and this area is open this area is open right.

Now, if I deposit my sensing layer my sensing layer right and after depositing sensing layer, if I dip this vapor in acetone, what will happen? The positive PR from all the area will get stripped off right. When it strips off the sensing layer over the photo resist will also get lift off. The sensing layer over the photo resist will get lift off. And if that happens, what will happen? If the photo resist gets left off, then we have sensing layer only in this area right. Because photo resist will lift off the sensing area from rest of the area.

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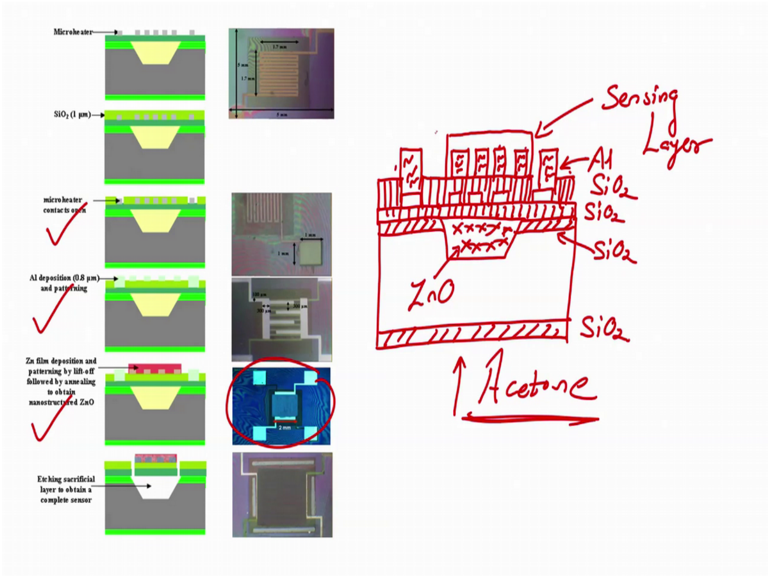

So, this is our sensing area sensing layer this is our sensing layer right.

So, we are now having a sensing layer, you can see here. Next step would be to create a window to create window such that such that we can remove this zinc oxide. So, let me just draw everything and then we can create a window. Now you know how to create a window, again using the photolithography that will be our last step to fabricate this sensor. So, when you deposit sensing layer, you can deposit there is a zinc oxide, you can use indium tin oxide like we discussed right.

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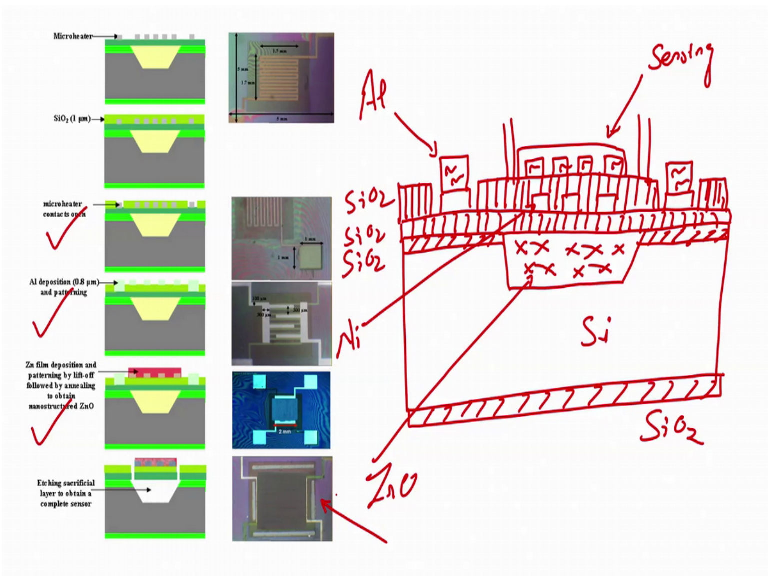

So, stay with me. It is the last step. Now you know what pattern is what right. What you are drawing here is silicon dioxide there was a micro heater and then we have aluminium right. And over aluminium we have our sensing layer. This is aluminium, this is our nickel, micro heater, this is zinc oxide, silicon, SiO 2, SiO 2, SiO 2, SiO 2 right. This is our sensor.

Now, what we are do? We have to create a window this area, this area four sides. You can see a top view here; you can see a top view here right. So, we are creating a window on four sides such that so, now, you know how to create a window right. You deposit photo resist, you load the mask, then you protect the photo resist and all the area, accept the area where we have to create a window right.

So, if you just want to say I can draw it. It is very easy to see. What I will do is; I will spin coat photo resist everywhere right.

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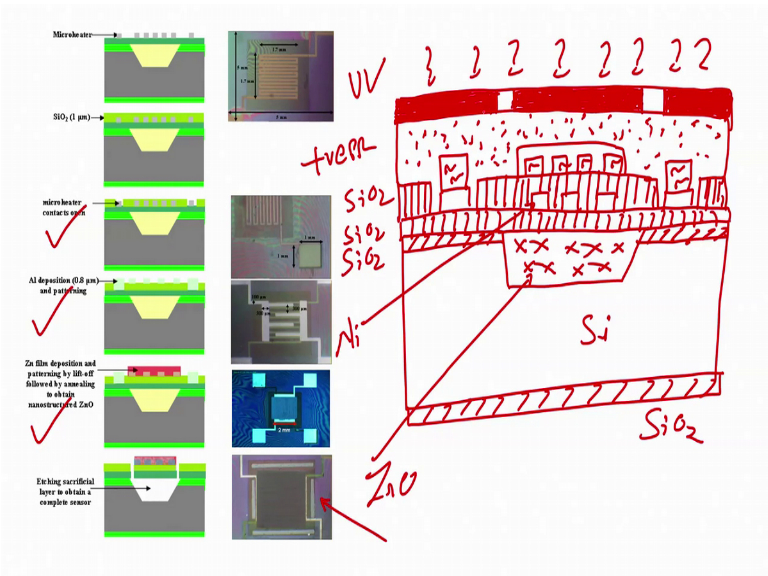

Then I will use a mask and I will protect photo resist in all the area except this two area right. This is a photo resist right, and I will protect my photo resist in all the area except the area where I want to create a window. Why want to create a window, because I want to a remove my sacrificial layer and to remove my sacrificial layer.

So, to remove sacrificial layer, I had to use this mask right. So, easy right now you guys understand that how we are fabricating sensor right or what is the process flow for fabricating a sensor right. What will learning here same thing, we can perform in the laboratory in a clean room. Now if I expose this vapor with UV, this is a positive photo resist. What will happen? What will happen? The photo resist in area which is not exposed will be stronger. See to create something takes time to destroy very few minutes right. So, creation is difficult destruction is easy to try to create or destroy. Try to always create the things.

Now you see here, these are work what we will get because we had window. So, let me just re draw it right. We have created a window you can see here right; you can see here you have created a window.

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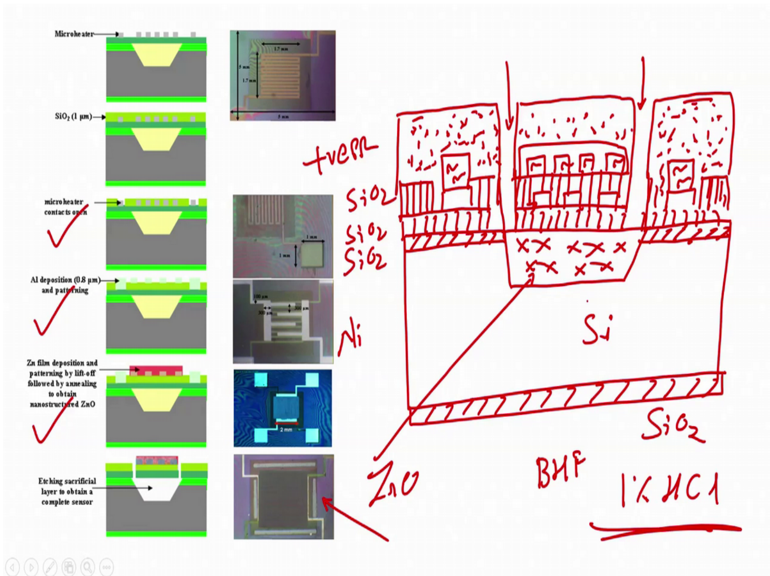

Now, what we will do? We will dip this vapor in BHF where we dip this vapor ion BHF. What will happen? We will have excess to our sacrificial layer right. We can now see the zinc oxide, because we have etched BHF right. We have etched silicon dioxide using BHF right. So, now, what will happen? If I so, first I have after creating a window, I have dip the vapor in BHF which is buffer hydrophilic acid which will etch my silicon dioxide right. And after I etch silicone dioxide I can see through this window a zinc oxide.

So, now I have dip this vapor in 1 percent HCl, 1 percent HCl. This is my positive photo resist is protecting the rest of the area right. Here it is not protected. So, if I dip this vapor zinc in 1 percent HCl the zinc oxide will get etched the zinc oxide will get etched and.

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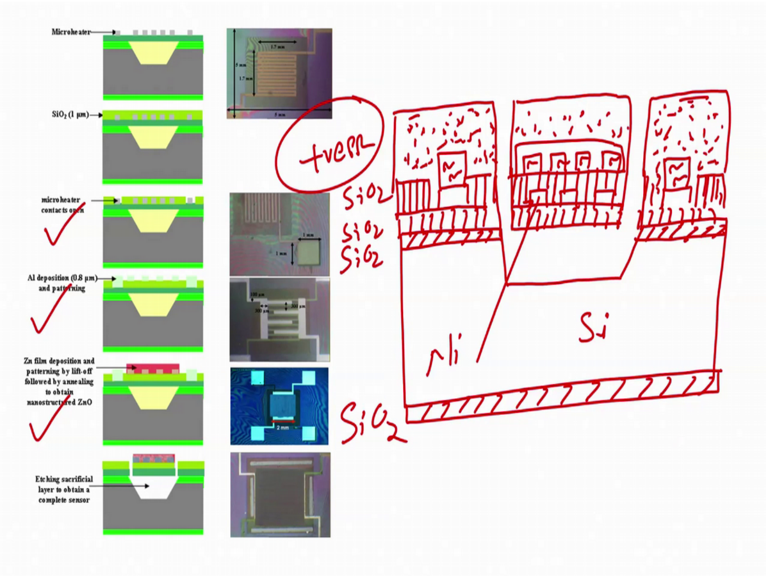

You will be able to see a cross section image and our sensor is realized, but, but the positive photo resist is here. So, positive photo resist we have to stripped off. How to stripped off that the positive photo resist? We have to dip this vapor in acetone. So, when I dip the vapor in acetone, then what will I have? Then I will realize my sensor right.

Now my sensor is realized. So, we have sensor and you can see the role of zinc oxide in the pit was to act as a sacrificial layer. This particular way of removing zinc oxide right and is your surface micromachining is your surface micromachining. We are combining bulk micromachining we surface micromachining to have a sensor with a on just 1 micron silicon dioxide, 1 micron silicon dioxide. The silicon dioxide that we have grown initially using that oxidation is 1 micron.

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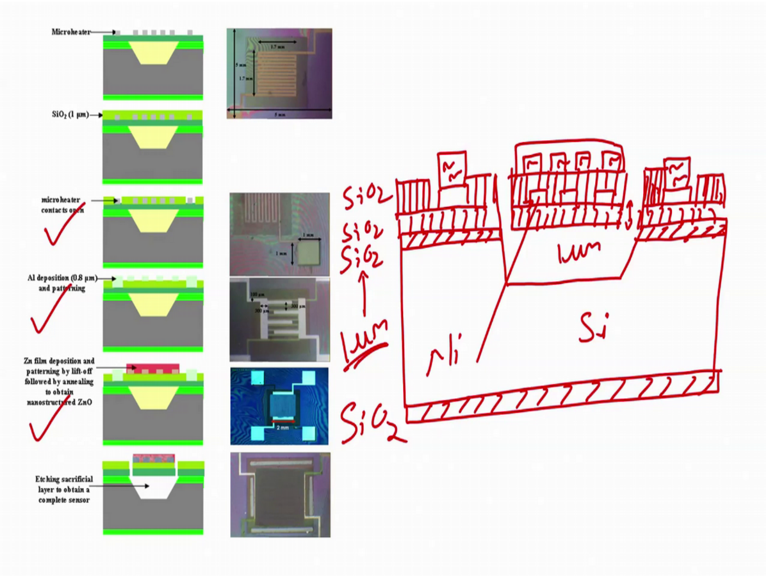

So, about one micron thick diaphragm or 1 micron thick bridge right, we have created entire sensor. So, where we are now? We did this and we reached to our final sensor that is what we wanted right. We have realized the sensor by removing the zinc oxide which was a sacrificial layer using 1 percent HCl alright. So, once you have this, then what you will do?

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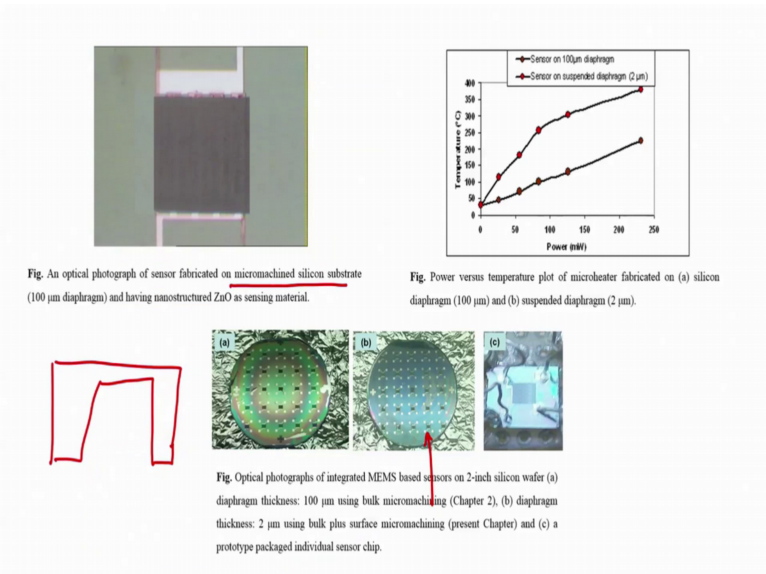

Once we have this, then what? Then we need to understand how the performance of the sensor right. So, this is an optical photograph of sensor fabricated on micro machine silicone substrate. You can see micro machined silicon substrate where 100 micron diaphragm and we are just this is 100 micron diaphragm is the structure. And the other one is our current sensor which is using bulk plus surface which is hanging right, this structure, this structure ok.

So, if you see if you see the performance right on 2 micron diaphragm about 1 micron or 2 micron diaphragm, the for 100 what will I consider? Let us 120 watt about 120 watt for the sensor on 100 micron diaphragm using bulk micromachining which is here right or which is here.

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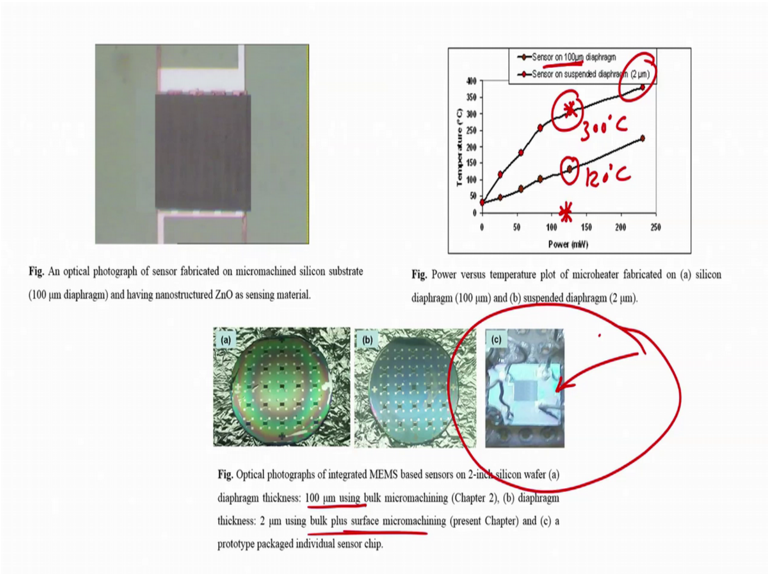

We can achieve a temperature of approximately 120 degree centigrade 120 degree centigrade. But for the sensor that is fabricated using bulk end surface micromachining bulk end surface micromachining. What is the temperature? About 300 degree centigrade you see, 300 degree centigrade, why? Because now the suspended diaphragm is only about 2 microns and this is the figure for bulk plus surface micromachining. You get it. That is advantage of fabricating a sensor using bulk plus surface micromachining technique right.

Now this is how we have connected the sensor right optical photographs of indicated MEMs based sensors. The messenger consists of a heater, interdigital electrode, sensing layer and a diaphragm either the diaphragm is fabricated using bulk micromachining or the diaphragm is fabricated using bulk plus surface micromachining.

So, one is 100 micron diaphragm using bulk micromachining or a diaphragm which is about bulk plus surface micromachining right; a prototype package individual chip is shown here right. Now once we have this, we have to see what kind of sensing layer we will be using it right, what kind of sensing layer will look like; if let us say you are talking about nano right.

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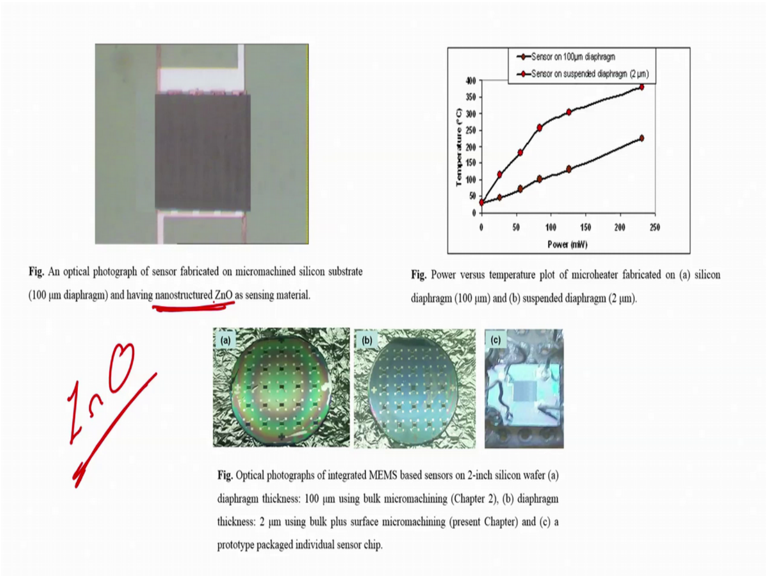

So, how can we have zinc oxide nanostructure zinc oxide? So, we will see that in the next module. In the next model we will see how we can have zinc oxide nanostructure. So, till now what we have seen? We have seen we have seen a bulk micromachining technique, then we have seen a surface micromachining technique right. We have taken two examples of designing a sensor or designing a process flow of a sensor right

The first example was using bulk micromachining technique and the second example was using bulk plus surface micromachining technique. Then we have seen if I have a heater on a bulk micro machined substrate which is about 100 micron. And if I have a heater on a bulk plus surface micro machined diaphragm which is suspended diaphragm about 2 microns or 1 micron, what is the advantage or what are the advantages? There are some disadvantages as well. What are the advantage advantages? That for the same power about 120 watts for the sensor that is created on 100 micron diaphragm, you achieve 120 degree centigrade.

But for the sensor that is created on suspended diaphragm, you achieve close to 300 degree centigrade. You see 180 degree centigrade more for the same amount of power when you reduce the thickness of the diaphragm that is obvious right. Because now, the heater has through heat only 2 microns compare 100 microns. So, the heat loss will be less heat loss will be less. So, what are the limitations here? The cons, there are the pros we have taken. But what are the cons are that in suspended diaphragm, the mechanical strength of the sensor is weak. Of course, compare to 500 micron 280 micron if it is 2 inch for 280 micron thick vapor. If I am using 100 micron thick vapor, the mechanical strength is reduced. But if I talk about 2 micron vapor, the mechanical strength is tremendously reduced. So, we can have a better power, but the mechanical strength goes down.

So, can you think of a technology where a mechanical strength remains same and still you can use less power to achieve higher temperature? We will be talking about this particular idea how to use slightly different technology not really technology, but just idea; so, that we can achieve a better mechanical stability right. Also will see how the nanostructured of zinc oxide can be grown with the help of zinc metal and to help you out that ok.

Once the sensor we fabricate right if we can fabricated a lot of devices, then what? We have to interface those devices with electronic modules to get actual data. So, what kind of electronic module you can design to read the sensor output right? Because if you are looking at sensor output in terms of resistance let us say. So, how would I know what is that resistance value and what rate resistance value corresponds to which kind of VOC and what is the concentration of VOC? For end user he or she would be interested in looking at the value of that VOC 10ppm, 20 ppm ok; that is it not 10 kilo ohm resistance, 2 kilo ohm resistance right or capacitance output can be in capacitance output can be resistance output can be impedance. So, my point is whatever the output of the sensor is we need to convert it to a readable format right from a end user point of view. So, you had to design electronic body.

We will just take a very quick example of a circuit, then we can use to interface with this kind of sensor to get a readable output right. Till then you guys read what we have discuss in this particular class right, and I will see you in the next module with the things that I will just told you. Till then you take care, have fun. Bye.