Fabrication Techniques for Mems-based Sensors: Clinical Perspective
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Lecture – 12
Micromachanics: Fabrication of VOC Sensor

Hi, welcome to this particular module and in this module, we will continue Micromachining. So, in the last module, what we have seen? We have seen Bulk Micromachining and Surface Micromachining. Now, let us see how can we use this Micromachining technique to fabricate sensor? And in this case, we will take example of VOC sensors. VOC stands for Volatile Organic Compounds.

Now, what do you mean by Volatile Organic Compounds? Compound that would be volatile right; so, can you give me some examples? Yeah. So, petrol, then kerosene, acetone, methanol, ethanol, butanol, propanol, Isopropyl, alcohol right; these are all Volatile Organic Compounds.

So, if I take a drop of this compound, if I put on my table it will evaporate. It will it will be immediately it is volatile. It will evaporate right. So, why we need to make a sensor? Of course, we are understanding micromachining and that is why we are take an example of this particular sensor, but we should also know why we had to make a particular device; what is a role of this particular device? So, the rule of fabricating or the application of fabricating these VOC sensors is in health because this course is focused on clinical research clinical perspective we will talk about health.

So, a person suffering from a lung cancer would emit a particular VOC in a higher concentration, then other VOC's. So, what is our breath consists of? Breath consists of lot of volatile organic compounds, carbon dioxide, humidity right. So, a healthy human would have a signature of VOC's below a certain level, but if you talk about a person suffering from lung cancer, that person will excel higher concentration of NO 2 or a person suffering from diabetes would excel a higher concentration of acetone in breath.

So, can we selectively detect this VOC which is acetone or NO 2 from rest of the VOC's? Yeah, of course, NO 2 is a gas; but we are the sensors can be used for detecting gases as well. And if we can do that, if we can selectively detect that particular gas whether it is acetone or this NO 2 from the breath, then we can qualitatively access that a person is suffering from a particular disease.

To quantify it, we should know how much concentration of that particular VOC or gas would be as the disease progresses. If you talk about diabetes, yeah as the blood glucose concentration increases; is there any correlation between the acetone concentrations increasing with blood glucose concentration increasing, if you have that correlation; then you can also quantify the data.

So, not only you can detect that a person is having diabetes, but how much amount of diabetes? What is it blood glucose concentration that can be correlated. So, the application of this particular sensor lies in this particular area when we talk about health. But, if I talk about other applications, VOC sensors are used or gas sensors are used in other applications as well.

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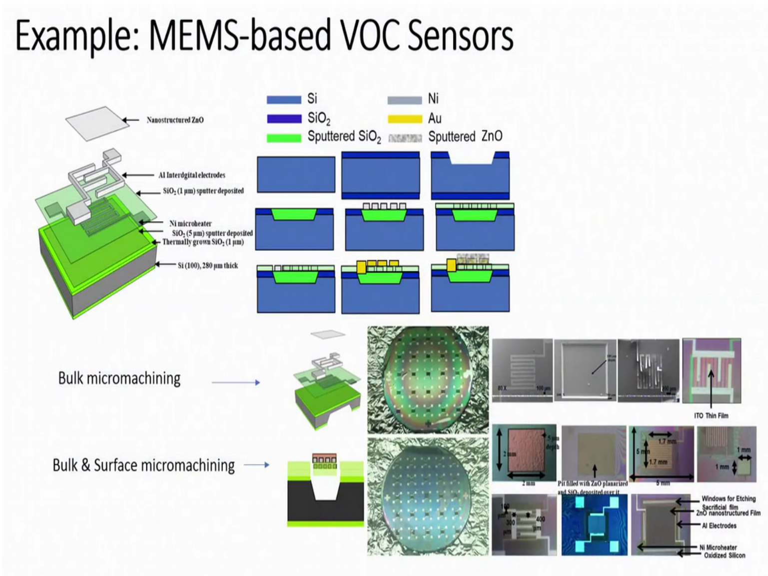

So, if you see the screen what we are showing you today and I always say we because any NPTEL course is not finished without teaching assistance right. They are integral part of any course and as a professor, I have to give credit to my team of teaching assistants and that is why I always say we are showing you on another slide right; whether they have prepared this slide or not I have prepared all the lecture notes, but they will be helping you out in your assignments and homework’s and other aspects during the course.

So, coming back to this slide, you see here, we will be talking about VOC sensor fabricated using Bulk Micromachining and this is the actual photograph of fabricated sensors using Bulk Micromachining and in this wafer, you can see array of sensors, many sensors fabricated on a single wafer it is oxidized silicon substrate.

So, if you see this particular figure, the on the oxidized silicon substrate is a blown up diagram; the first structure is a heater. First structure is heater. So, we have here heater you can see SEM image of a heater. On the backside you can see this diaphragm right, this etching that we have created. We had done this etching using Bulk Micromachining. This etching on the backside to create a diaphragm, we have used Bulk Micromachining.

So, this etching on the backside, you can see here in form of a pit. This heater is made using nickel, when we heat the heater right when we apply power, the heater will get heated up and what is the maximum temperature that the heater can achieve? The so that is why we keep on applying the power and a certain point, you will see that the heater starts breaking.

So, what is the temperature at which what is the maximum temperature achieving capability of a heater that is what we wanted to measure. Next part, if you see next part is your inter digitated electrodes. Next part is your inter digitated electrodes or we call IDEs right. So, over this IDEs, we form a thin film of indium tin oxide; we form a thin film or we deposit a thin film of indium tin oxide.

So, let us see how this process is done? How can we have we get this sensor, let us see in the next slide. And then, we will come on Bulk plus Surface Micromachining ok.

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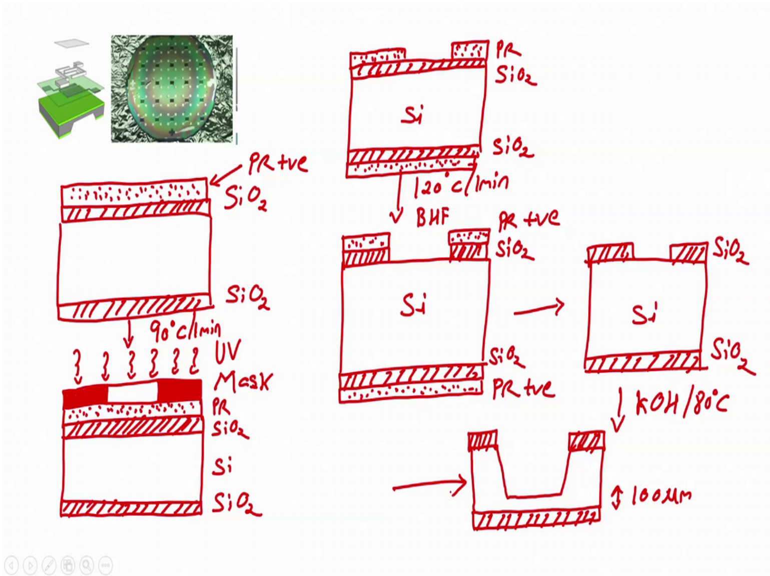

So, the starting before would be oxidized silicon substrate. Starting would be always silicon and then, we grow oxide that is why I said oxidize silicon substrate right. So, we have oxidized silicon substrate, then we perform photolithography. So, for performing photolithography, the next step should be spin coating photo resist. After spin coating photo resist, next step would be now you guys should know right because we have (Refer Time: 10:10) photolithography.

Next step should be mask right. We lower the mask for creating the window; that means we will create a window by etching silicon dioxide because finally, we want to create a diaphragm and then, we are going to fabricate the remaining structure of the sensor right. So, this is my mask; after having mask, loading mask, next step would be to expose wafer with UV light, exposing wafer with UV light right. What is the next step?

Next step would be of course, you see when I when I am telling about we are spin coating positive photo resist, it is it should be assumed that after spin coating, we will be going for soft make right; after positive photo resist, we have to go for soft make. So, I am assuming that you guys now know it and that is why I am not writing it ok. 90 degree centigrade 1 minute, we know it right and then, after mask we had to develop the foot develop this wafer in a PR developer.

So, when you develop the wafer in photo resist developer, you will get you will get a structure like this. After that next step would be harbic. Again, I am assuming that you guys know; but let us write it down for 1 time Hebraic; after Hebraic you have to dip the wafer in BHF, dip the wafer in BHF. When you dip the wafer in BHF, silicon dioxide will get etched right; silicon dioxide will get etched. Now, if you see it should get etch on both the sides right, on both the sides.

Now, what I will do is when you perform this PR developer; after PR developer and before after PR developer and before harbic, I will just spin coat photo resist on back side also. And then, perform hard baking ok; spin coat photo resist on backside and then, perform hard baking and then, we will go for BHF. This will protect my wafer, this will protect my oxide on the other side of the wafer right.

So, what I have? I have PR. I have SiO 2. I have silicon, again I have SiO 2 and I have positive photo resist on both side of the wafer right. Next would be I will dip this wafer in acetone; dip this wafer in acetone; when I dip the wafer in acetone, what will happen? PR will get stripped right.

PR will be stripped off. Sorry right. PR will be stripped off. Next step would be etching wafer in KOH 80 degree centigrade to obtain diaphragm. Sorry about this. I mean write here, right. Let us say this diaphragm is 100 micrometers right.

So, we now have diaphragm right with 100 micrometers thickness, easy until here is very easy right. So, if I want to further work on this, then let me copy this. So, we are on the same page ok. So, now, we have this structure right; this structure the next would be if I reverse that structure, what will I have?

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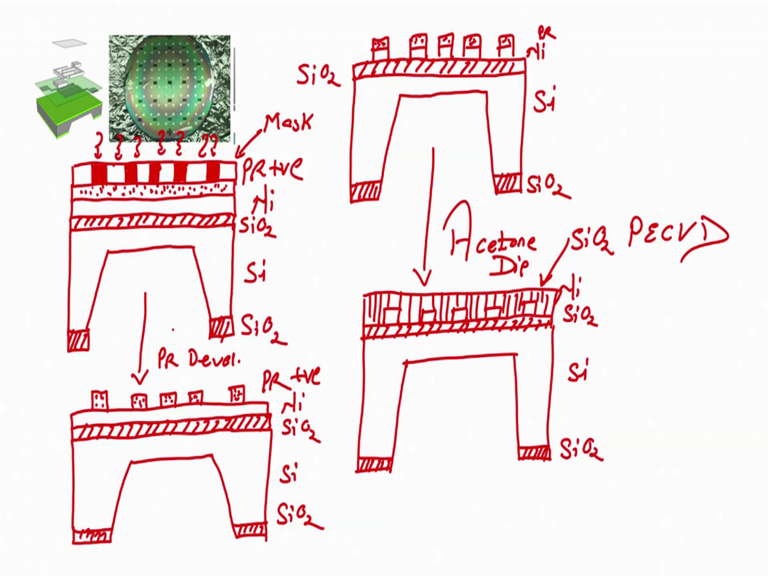

I will have I will have oxidize wafer with a diaphragm with a diaphragm and this angle would be we know it 54.7 degree right; angle would be 54.7 degree.

Now, next step, after we have diaphragm the first step on that front side would be heater; front side would be heated. So, we can now deposit nickel; is a nickel, SiO 2, Si, SiO 2 or nickel, I will spin code my photo resist. How I am going to deposit nickel by using e-beam Evaporation right.

By using e-beam Evaporation, we can deposit nickel right and this is my positive photo resist. Next step, next step, we all know I will just dry on the dried on the same structure right; next step will be after positive photo resist spin coating soft bake 90 degree 1 minute hot plate, then we should have, we should have heater right; we should have heater.

So, for having heater, we have to load the mask; for heater after the after depositing nickel, we need to fabricate a heater. We had a patent nickel to fabricate a heater, for fabrication of heater, we have deposited photo resist and then, we have loaded a mask right. After loading mask next step we all know is UV exposure right.

After UV exposure, next time would be PR developer. So for PR developer, when we develop a wafer with a photo resist, when we develop a photo resist; then photo resist we will stay in this area. Why only this area because we are using positive photo resist and the area which is not exposed right will be stronger. So, we get this particular pattern.

Next step, after positive photo resist of develop in the photo resist, next step would be hard baking; after hard baking, next step would be etching nickel. So, if I etch nickel, what will I have? If I etch nickel right, then nickel will get etched wherever photo resist was not there right; wherever the photo resist was not protecting nickel, it will get etched.

So, this is photo resist, this is nickel; then, we have silicon dioxide, then we have silicon, then we have silicon dioxide. After nickel, next step would be Acetone Dip or stripping of photo resist, when we strip of the photo resist; what we will have? By strip of the photo resist, I will have my micro heater ready. So, nickel SiO 2 silicon SiO 2 correct. I have my micro heat already.

Next step, would be to form inter digitated electrodes. Now nickel is heater, material for heater right; but nickel is also metal, nickel is a metal. So, now, if I want to fabricate an inter digitated electrodes on heater, I cannot do it right because it will be shorted we cannot have metal and metal. So, what we can have? We can have an insulating layer between two metals. So, if you come back to the screen, the next step would be next step would be to grow silicon dioxide.

So, let me draw silicon dioxide with vertical lines like this. This is we have actually grown silicon dioxide with help of PECVD. PECVD, you will see in the chemical vapour deposition section, we will see why plasma enhanced chemical vapour deposition is used to grow silicon dioxide? So, silicon dioxide, we are growing. Now, we have to perform photolithography which you know like the positive photo resist, then we go for soft baking; then, we go for developing of PR after positive photo resist we go for soft baking, then we go for mask UV exposure, PR development and then, we finally, etch the required area right.

Now, what we are doing here is that the unwanted idea we etch right. So, here what we will do is we do not want our nik our silicon dioxide to cover the contact area right; we do not want the silicon dioxide to cover the contact area.

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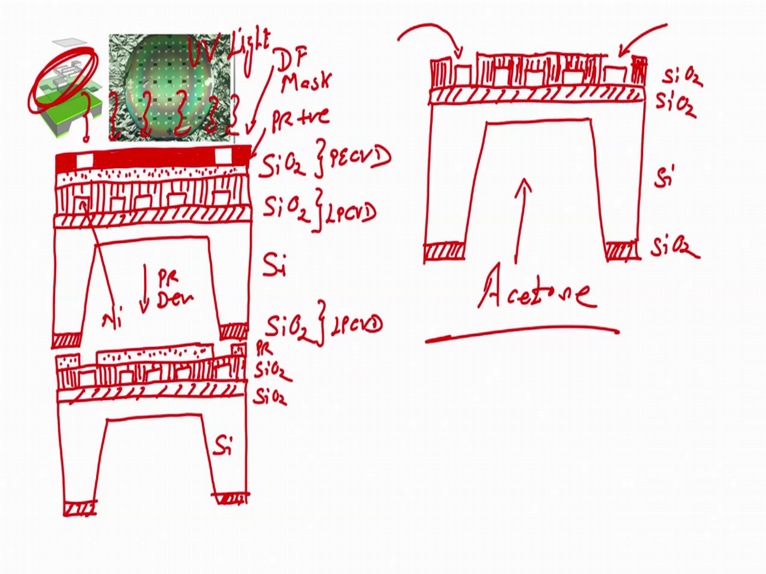

For that what we will do? So, let us draw here. So, these are contact ok. These are heater contact here and here. These both are heater contacts ok. So, what we have right now? We have silicon dioxide which is grown by plasma enhanced chemical vapour deposition. This silicon dioxide is grown using wet etching that is low pressure chemical vapour deposition. This one is done using PECVD right and we have nickel micro heater, we have silicon already we have written here.

After this, next step would be spin coating of photo resist spin coating photo resist positive; next step would be we do not want we do not want the silicon dioxide on the contact pads right, otherwise we cannot apply power to the heater. So, we will have a mask, we will have a mask which is dark field mask, in this case we are using dark field mask; earlier all the cases we were using a bright field mask right, why? Because we want to protect silicon dioxide in all the areas on the micrometer except contact pads; except contact pads right.

So, what is this mask? This mask is dark field mask. After loading dark filed mask, next step would be expose right; expose the wafer with UV light. Expose the wafer with UV light, when you expose the wafer with UV light and then develop the wafer right, expose the wafer then develop the wafer. So, PR developer you develop the wafer, PR will develop like this and you can see that we can access now silicon dioxide which is grown using PECVD right correct.

So, next step would be next step would be hard bake and then and then we have to etch silicon dioxide; we have to etch silicon dioxide. So, we will dip the wafer in silicon dioxide etchant and you guys know, what is silicon dioxide etchant? Silicon dioxide etchant is buffer hydrofluoric acid; buffer hydrofluoric acid which is BHF right BHF. And very clearly see that silicon dioxide is etchant from the contact pair of the heater right silicon dioxide is etched from the contact pad of the heater.

So, next step would be to dip this wafer in Acetone right. So, when you dip the wafer in acetone, what will happen? The photo resist will be stripped off; photo resist will be stripped off. So, let us remove the photo resist, right. Photo resist will be stripped off

So, now what you have is silicon dioxide protecting your micro heater right except in contact area. So, now, we if we apply power here or voltage here right because of the resistance of the heater current will flow and heater will heat up; heater will heat up. But our our idea is not to stop here; but our idea is to now for fabricate inter digitated electrodes; you can see here inter digitated electrodes. So, how to fabricate inter digitated electrodes right?

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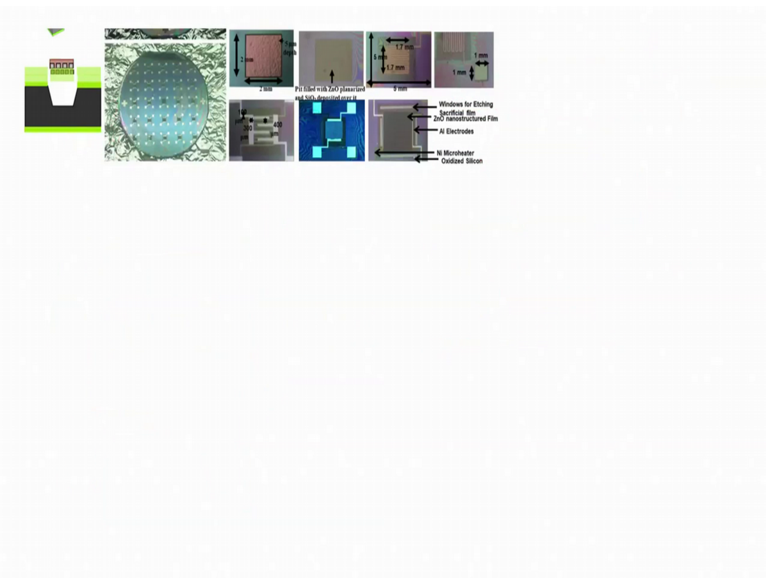

How to fabricate this inter digitated electrodes?

So, let us see how we can do it?. So, I am just deleting this slide. So, that we have we can work on the inter digitated electrodes on the micro heater. Now we have insulator right;

we have insulator. So, we can now deposit a metal right that can be used for fabricating inter digitated electrodes. So, what is this metal? Let us use aluminium as a metal for fabricating inter digitated electrodes and just removed. So, we can start from a wafer.

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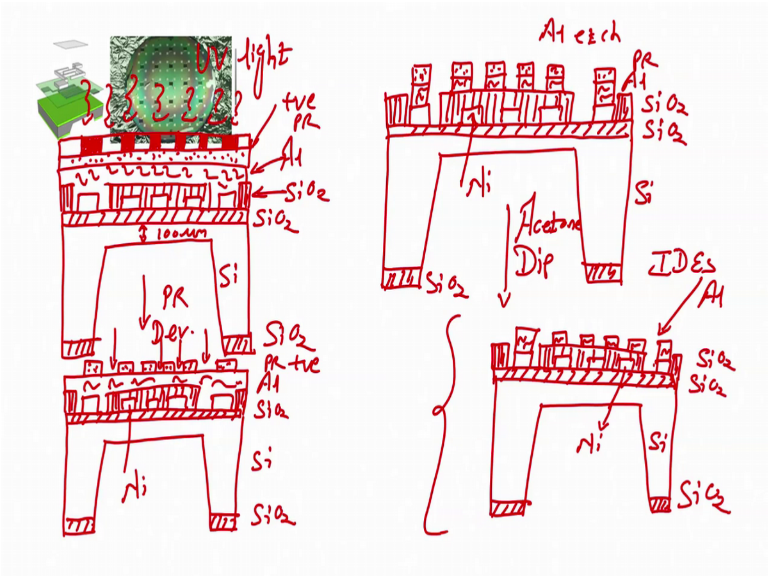

So, I will draw here or wafer and wafer has a micro heater. This is our oxidized silicon wafer with diaphragm right. It has a micro heater and silicon dioxide protecting the micro heater right ok. What is the next step? Next step is we have to create inter digitated electrodes on this structure. So, we will deposit a metal ok.

So, let us have this pattern for our metal or metal is nothing but aluminium. This one would be our SiO 2 from PECVD. This is our SiO 2 from wet oxidation and PECVD right and this is our diaphragm 100 microns. Now, we want to create an inter digitated electrodes. So, what we want finally is a structure that should look like this. This is what we want from here from this structure right.

So, next step would be after this next step is spin coating photo resist right. So, quickly will spin coat the positive photo resist? After positive photo resist, we had to perform soft bake. After soft bake, we will use a bright field mask and load it onto this wafer like this, then we will expose our wafer with UV light right; expose our wafer with UV light after that vapour form PR developing; when you perform PR developing, you will have oxidize silicon wafer with a micro heater silicon dioxide aluminium and photo resist right; positive photo resist. So, the area which was not exposed did not get became stronger, it did not get etched or it did not get developed in the photo resist developer.

Next step would be hard bake followed by aluminium etching. So, when we performed aluminium etching, then what we will have? Performing aluminium etch right this is what we will get. So, we have photo resist, we have aluminium, we have SiO 2, we again have SiO 2; we have silicon and we have SiO 2 at bottom right and then, we have here our nickel micro heater correct. Because the photo resist will protect the aluminium and thus, the aluminium which was not protected with have you can see here right between the photo resist we will get etched.

Now, after this what is the next step? Next step would be Acetone dip. So, when I dip by wafer in acetone, what will I have? I will have my inter digitated electrodes over insulator over micro heater over oxidized silicon substrate and that is having a diaphragm. Still we have not finished fabricating VOC sensor I enjoy it a lot you know because at a at a point says that ok, it looks like let this is a last slide, we have one more slide and without something there you cannot sense right without sensing layer you cannot sense. So, and there is a roll of micro heater, I will talk about it; micro heater, insulator, inter digitated electrodes last step.

Let us do it. So, come back to the slide right. Let me just quickly rub it down. So, last step would be to deposit a sensing layer and that I was a sensing layer would be indium tin oxide um. It can be any other layer; it can be any metal oxide, it does not matter. It can be nano structure of oxide or metal oxide nano structures; it can be a thin film of a material right whatever sensing layer, you want to use depending on your application of what gas you want to sense, you can use that particular sensing layer right.

So, several sensing layers such as like indium oxide, tin oxide, indium tin oxide, zinc oxide, tungsten oxide right are used for used as a sensing layer on the top of inter digitated electrodes form a sensor.

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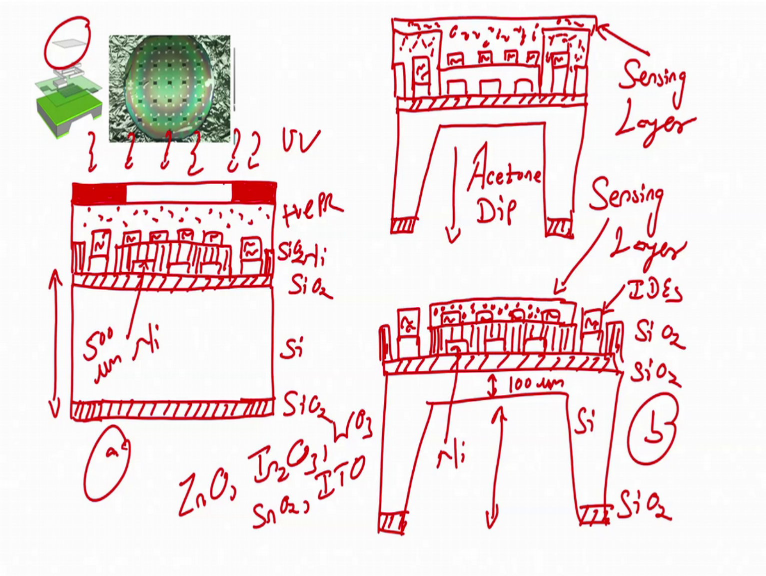

So, let us write down let us draw, this is a last step right; this is a last step. So, we have SiO 2 Si SiO 2. We have nickel, SiO 2; then, we have inter digitated electrodes ok. Now instead of performing a standard photolithography, I will show you something called liftoff technique. What? Lifting off; lift off technique ok. These kind of techniques are used when you think that the etching layer, the etchant of the top layer will affect the bottom layer below it. What do I mean by that let us see here?

Suppose, I say that I have a wafer with aluminium right and I have SiO 2 which I want to etch in a way that it should look like aluminium is here and SiO 2 only stands here ok, you got it right. If I have this wafer with SiO 2 covered on aluminium inter digital electors and I want a wafer which would look like this; which is my aluminium and SiO 2 should only cover these two parts of the design.

So, I have to perform lithography right and finally, I had to dip this wafer in BHF correct. So, why BHF; Because BHF is the etchant for silicon dioxide. So, if I want to if I dip this wafer in BHF, what will happen you guys know? The aluminium this aluminium which is exposed will get etched in BHF. The BHF will etch aluminium as well.

So, this technique cannot be used right; this technique cannot be used because my BHF is going to affect my aluminium correct because you see when I perform lithography, I will only protect I will only protect this area with photo resist right because I only want to protect silicon dioxide in this region. So, this area will not get protected, when this area will not protected; that means, said it will look like this. See this PR in silicon dioxide if I put this wafer in BHF, this BHF will etch silicon dioxide here, here when it reaches aluminium it will also etch aluminium.

Thus, this technique cannot be used. So, what is an alternative technique? What is an alternative technique? Alternative technique would be if I want to have if I want to have a wafer with aluminium and SiO 2 only in this part, then how about this? I take the wafer with my aluminium inter digitated electrodes right and I coat the PR directly photo resist I coat the photo resist in such a way that my photo resist will cover only these two electrodes.

It will cover this is my photo resist. What I want? I want silicon dioxide; I want aluminium. So, let us have aluminium like this; it is easy to keep the pattern same right. I have my silicon or oxidized silicon wafer. Let us say and my conventional way of performing photolithography like the one, we discussed just now; will affect my aluminium because silicon etchant affects aluminium.

In that case what I am doing is photoresist right; photoresist is pattern in this kind of way and then, on this photoresist I will deposit or I will grow silicon dioxide. I will deposit or I will grow silicon dioxide alright, then what I will do? I will dip this wafer, this one this wafer this wafer in Acetone in Acetone. What will happen that the photoresist will get stripped off in acetone. So, photoresist this much area and this much area will get stripped off because photoresist will get stripped off. So, when this photoresist stripped off, the silicon dioxide on photoresist would also get lift off; you get it?

So, when this happens when I dip the wafer in acetone, what will happen is that this photoresist, this area will get stripped off; this area will get stripped off. When this area stripped off, this will take the silicon dioxide on top of it as well; this will take silicon dioxide on top of it as well; resulting in silicon dioxide that I want in this particular design.

This is called lifting off; this is called lifting of the silicon dioxide; lifting off of the photoresist. Same lift off, we will use in this particular example. So, let us see. Lift off technique, we will use lift off technique is used when the final or the top layer etched will affect the bottom layer pattern right; top layer etched will affect the bottom layer.

So, now what I want? I want this material to get deposited on inter digitated electrodes right. So, I will spin coat; I will spin coat photoresist, then perform soft baking; then, I will load a mask that is protects my photoresist in this particular fashion. Then, I will perform UV exposure right; then, PR developer, PR developer.

So, I will just try it over here. I will get this kind of pattern right. PR will get developed because it is a positive PR right and then, then I will deposit my sensing material on this. This is the top layer like circle is my sensing material. After this, I will dip this wafer in acetone, when I dip this wafer in acetone, what will I have? I will have my VOC sensor; VOC sensor ready to be utilized ready to be utilized.

So, when I deposit something there on this kind of pattern, I will have finally, when I put when I dip the wafer in acetone, I will have a sensing layer. I have inter digitated electrodes right, I have silicon dioxide, I have silicon diaphragm and I have my nickel micro heater. You see this is your sensor, this is your complete sensor and Bulk Micromachining is where I have etched my silicon I have etched my silicon.

Now, the question that arises is why to do Bulk Micromachining? Why not to directly use oxidized silicon like this? Why to perform this Bulk Micromachining right? So, you can see that there is a heater here; we are using nickel as a heater right. Why we are using heater? Because if you heat the metal oxide materials, then at a higher temperature it will show a better sensitivity; at a higher temperature the metal oxide semiconductor shows a higher sensitivity for different volatile organic compounds ok.

So, there is a subject called thin film physics, if you understand that; then you will understand why and how the grains will create a depletion layer across it and as you increase the temperature based on reducing and oxidizing gases, the electrons will either be released or it will be the conductivity would increase for reducing gases; for oxidizing gases, the conductivity would decrease and resistance would increase.

So, this is a different subject. However, you just understand that for a gas sensor to work we require it to heat at higher temperature if we are using metal oxide thin film materials such as zinc oxide, zinc oxide, indium oxide, tin oxide, indium tin oxide, tungsten oxide right, we require higher temperature for better sensitivity.

So, for higher temperature, we are integrating a micro heater if you can see in the design right. So, we have indicated a micro heater. Now, we need to have inter digitated electrodes for this sensing layer right so that we can measure what is a resistance of the sensing layer; that is why we have inter digitated electrodes on which we have the sensing layer.

Now, since we have a micro heater, if we have to heat a wafer which is 500 microns in thickness or you have to heat a wafer which is 100 micron in thickness because we are creating a diaphragm; in which case the power consumption will be less? The power consumption will be less in let us say this I say and this I say b; then, in case of b the power consumption would be less.

Thus, Bulk Micromachining is useful to reduce the power consumption by the sensor. You guys got it? This is the application of Bulk Micromachining and when you see this, you will be able to see a structure similar to the one that shown in figure here. Here, we have used indium tin oxide right. Here we have used indium tin oxide.

Now, in the next module; so in this module, what we have learnt? We have learned how to perform; how to use Bulk Micromachining to create a sensor that can be used for sensing VOC's. In next class, let us see, how can we perform bulk and Surface Micromachining to create structures or to create a sensor that can be again used for VOC and then, we will see what is the alternative technique so that you see when you reduce the diaphragm when you when you reduce the thickness of silicon, the power consumption goes down.

But, the mechanical strength of the material also goes down. So, how can we retain the mechanical strength and still reduce the temperature? Mechanical strength reducing not temperature; reducing the power. Mechanical strength should be intact and the power should be less; how can we think about such kind of technology?

So, we in the next module, we will see Surface plus Bulk Micromachining and we will also see this novel technique plus we will also see how different actuators are fabricated; how the cantilevers have fabricated; what is a DRI structure; how wet versus dry etching can be compared? Thin film deposition and we will see CVD techniques; 4 basic types such as ALD, PECVD, LPECVD and metal oxide then, we will also see MOCVD. So, this is what we will do.

So, till then, what I will say is just go through all the slides that we have discussed till now and just understand how you can perform photolithography and how you can use Bulk Micromachining. In the next class let us see how we can use surface micromachining? So, till then, you guys take care. Have fun. I will see you in next class. Bye.