Electronic Systems for Cancer Diagnosis
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Lecture – 64
Fabrication process flow for a metal oxide gas sensor

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Hi, welcome to this particular lecture. Now, if you see, what we had to do is that I will show it to you, how can we design a gas sensor, and what are the process flow for designing that particular sensor ok. So, let me show it to you on the slide. Suppose, I want let me get first show, it you here if you can come back to the screen, I am holding a sensor suppose, I want to fabricate this sensor. Now, I am not interested in understanding the casing, I am interested in understanding what is within the sensor ok. So, here we are looking at the video which will help us to understand what is there within this particular sensor.

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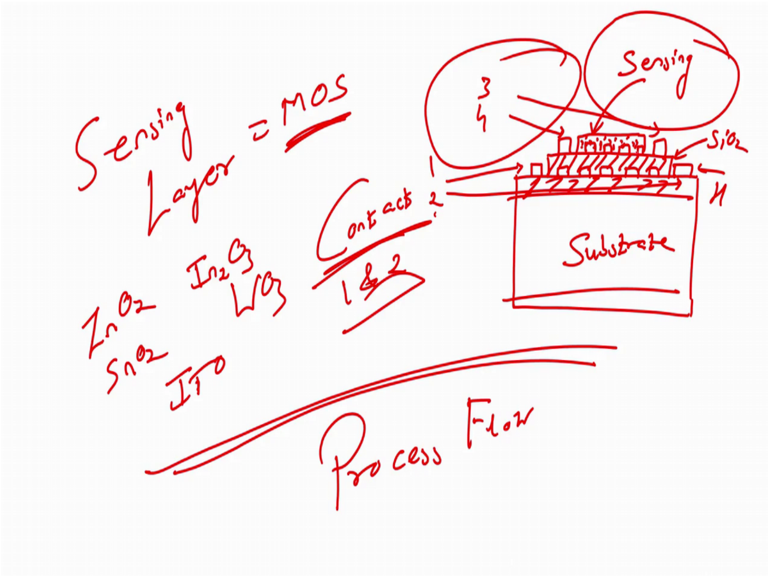

So, let me just show it to you, again if you can go back to the slide. So, what are we were talking about, we were talking about that we have a sensor, and sensor has four points. So, the first point should be a heater, first two points should be heater right. These are the contacts to the heater, heater contact 1 and 2 right. This is 1 and this is 2.

Then on this heater, there should be some kind of oxide or insulating material. On this insulating material, there should be a sensing layer. And for sensing layer, there should be again a electrode. So, this one would be our sensing layer. This one and this one would be over 3 and 4, these are electrodes. This is sensing layer, sensing layer alright. This is our substrate alright.

So, I want to design a process flow; I want to design a process flow to fabricate, this particular sensor. The sensing layer should be metal oxide semiconductor. So, I can use zinc oxide, I can use tin oxide, I can use indium oxide, I can use indium tin oxide, I can use tungsten oxide right several way of doing ok.

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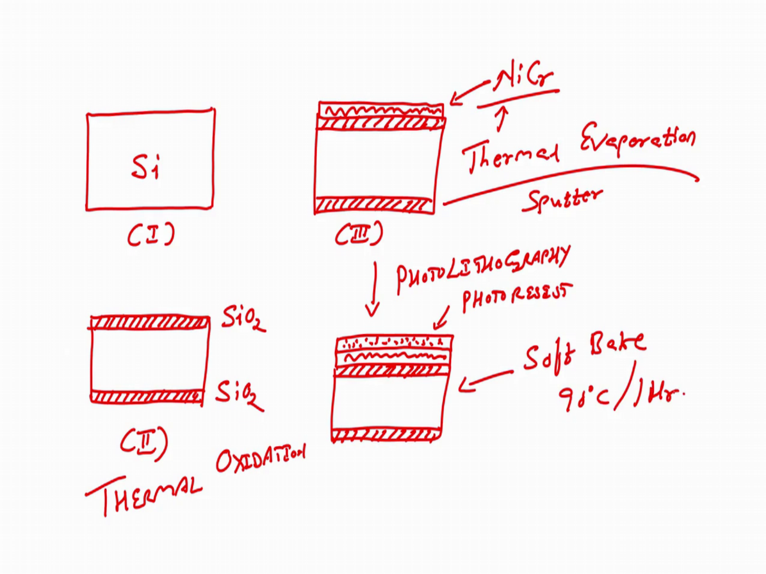

So, let us see the process flow. We start with a substrate start with a substrate which is silicon, then we grow oxide, so this is stage 1, stage 2. Stage 3, how you grow oxide, we grow oxide with the help of thermal oxidation all right, this is our stage 3. Stage 3 what we do? We will deposit a metal, this metal is for our heater, so I will say nichrome alright.

Let me give some design to this, so that we can understand the difference. After this, I need to perform a photolithography technique, photo lithography technique to fabricate a heater. So, what I will do is the first step after this would be, I take a substrate which is already having a metal, how will deposit nichrome? We deposit this nichrome using thermal evaporation or sputtering all right. So, we have this metal. On this metal, I will spin coat photoresist, what I will do ask pin code photo resist. After spin coating photoresist, I will bake this which is called soft bake this at 90 degree centigrade for one hour ok.

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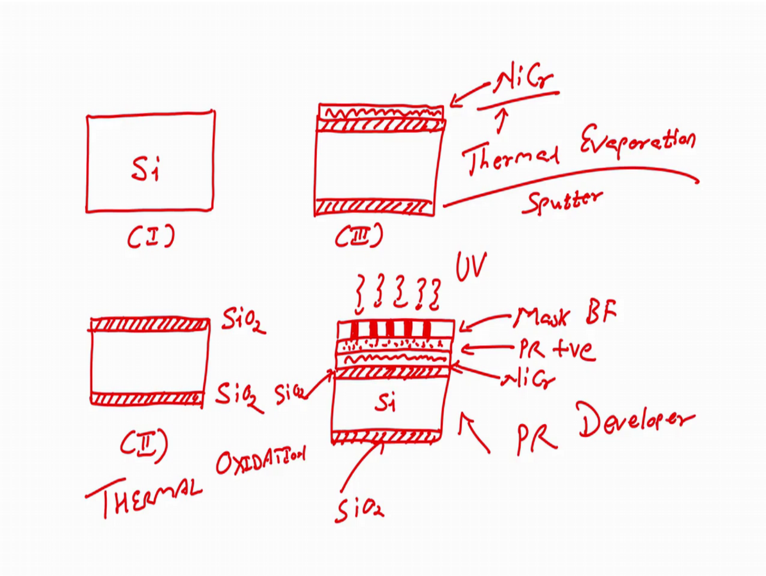

Next step is so you let me write down here, this is my photoresist right. This is my nichrome, this is silicon dioxide, this is silicon dioxide silicon and on this, I will have a mask. And that mask is my brightfield mask, you have seen in the lithography section right, what is the importance of brightfield, what is the importance of dark field right. So, this is my bright field mask, and this photoresist is positive photoresist ok.

Next step is I will expose this wafer with UV with UV light that is why, it is called UV lithography all right; expose this wafer with UV light. After exposing the wafer, I will dip this wafer in photoresist developer. After exposing this wafer, I will leave this wafer in photoresist developer.

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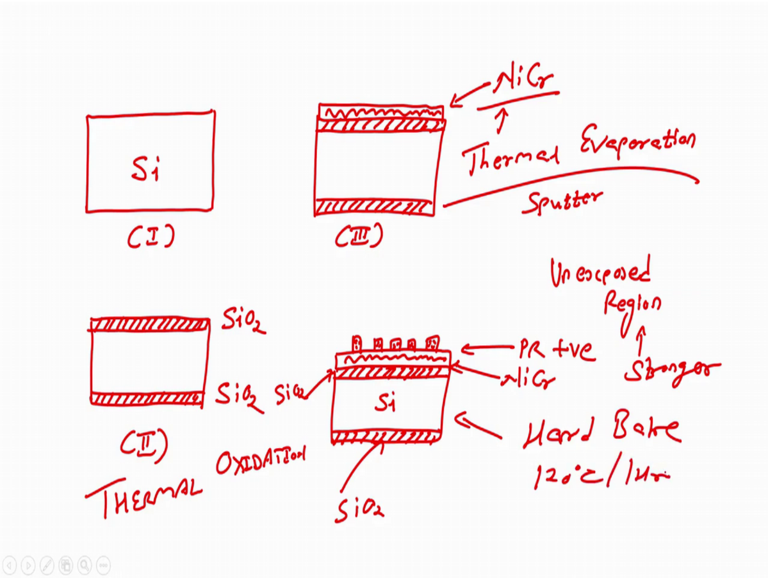

When I dip this wafer in photoresist developer, what will happen that the unexposed area, unexposed area will become stronger, and the exposed area will become weaker and get developed why, because it is a positive resist. For the positive PR, the unexposed region becomes stronger, we know that right. So, this photoresist is here. Now, after this I will do a hard bake, I will perform hard bake, hard bake is done it 120 per 1 hour. When I perform hard bake, after this I will dip this wafer in nichrome etchant nichrome etchant.

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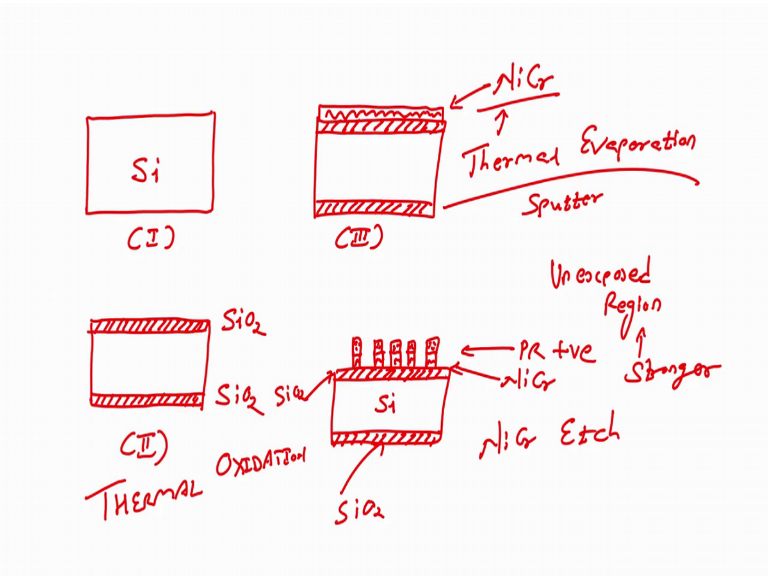

When I dip this wafer in nichrome etchant, what will happen? The area which is protected by photoresist area which is protected by photoresist will remain, and the area which is not protected by photoresist will get etched all right.

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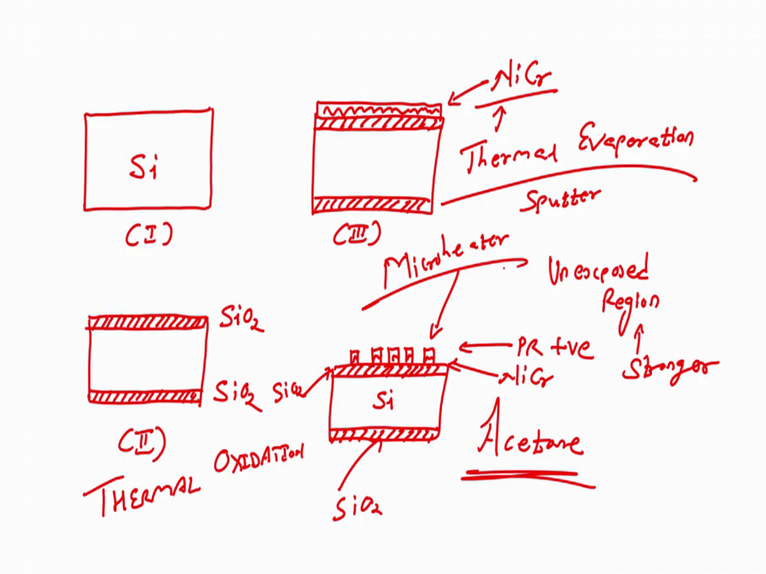

After nichrome etching, next step is I will dip this wafer in acetone, I will dip this wafer in acetone why, because when I dip this wafer in acetone, I will strip off my photoresist, I will strip of my photoresist. Now, what I have is a sensor or as a with a substrate with a micro heater, I have a substrate with micro heater. But, what I want? I want a substrate with micro heater this is your heater context 1 and 2 right, and a sensing layer and electrodes right.

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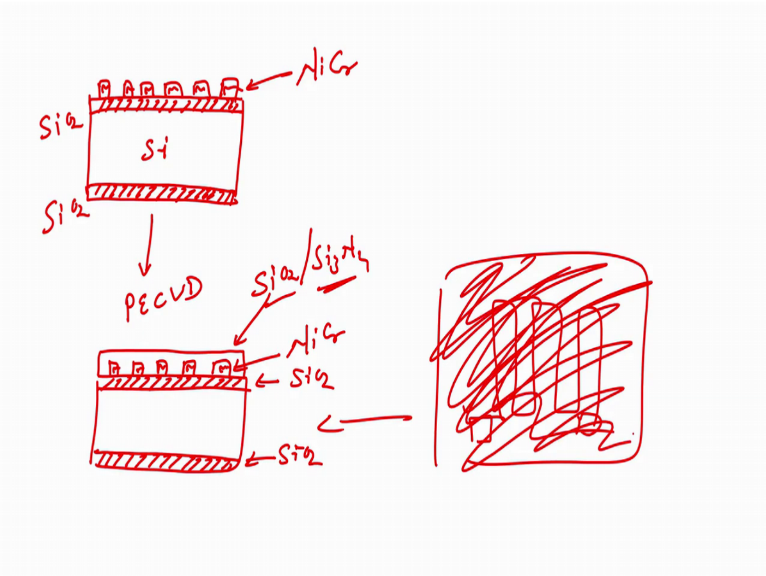

So, once I have a substrate with micro heater, let me draw it here all right. This is all silicon dioxide, this is silicon, silicon dioxide, silicon dioxide, this is our nichrome heater ok. Now, what we will do, we have to have insulator, because we cannot directly deposit metal oxide semiconductor on the micro heater.

So, for having insulator, we have to use PECVD PECVD. If I use PECVD, what will I have, I will have my heater with an insulating material. So, there will be insulating material on the heater ok. This insulating material can be S i O 2 or S i 3 and 4 silicon dioxide or silicon nitride. This is my nichrome, this is my silicon dioxide, this is my silicon dioxide. Now, can I directly deposit my semiconducting material on this particular insulating material S i O 2 and S i 3 n 4 no why, because I am not able to access the contact area of the heater.

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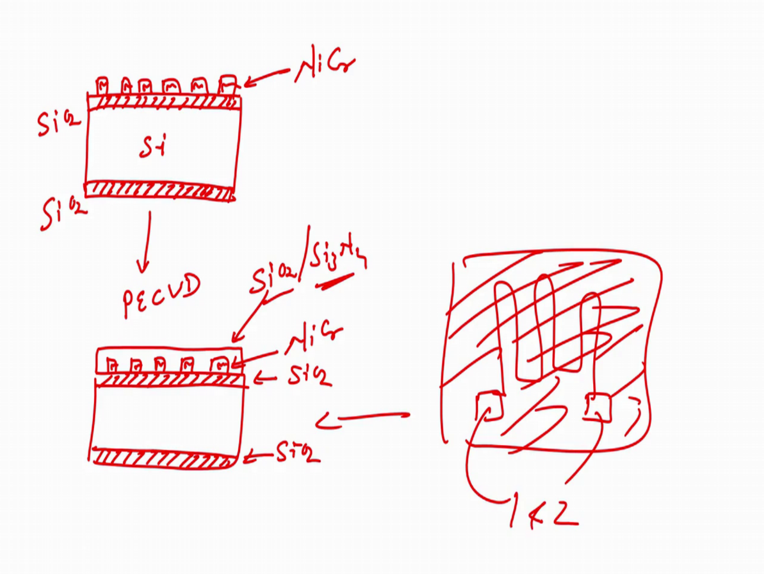

If I draw the top view of this particular slide, my top we will look like, I have a heater and everywhere there is a oxide everywhere there is oxide. So, I cannot hit the heater, so for that what I have to do for that I have to open the contact of the heating material that means that everywhere, there can be silicon dioxide except on the heater contact except on the heater contact. Except 1 and 2 everywhere should be silicon dioxide. So, for that what we need to do, we have to perform again a photolithography, so that we can open the contact or heater contacts right. You can open the window, and we can have the heater context.

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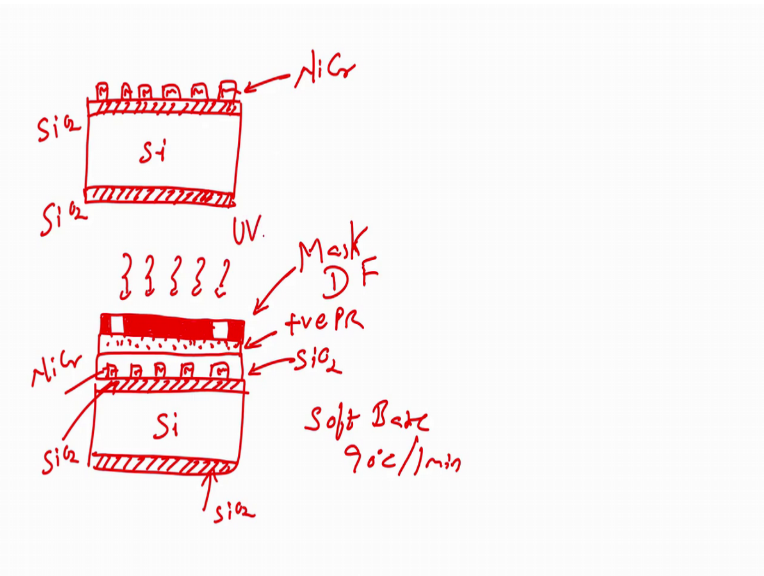

Now, let us see, how we can do that all right. So, after this, we will have photoresist. So, if I write it down, so you do not get confused, this is my insulating material, let us say silicon dioxide. This is my heater, which is nichrome, this is again silicon dioxide, which is thermally oxide, this is silicon dioxide, again thermal oxidation, this is my silicon, which is my substrate, and this is my positive photoresist right.

Now, I will after positive photoresist spin coating positive resist, what I will do? I will soft bake, do not forget the steps soft bake; soft bake is at 90 degree for 1 minute. If I have written somewhere one R, it is not correct just understand 90 degree 1 minute, 120 degree 1 minute not hours 90 degree 1 minute, 120 degree 1 minute.

After this, I will lower the mask, and this time my mask should be my mask should be such that I want this area to be opened which area the contact area of the heater right. The heater windows the contact area to the heater windows, it should be opened. So, this is my mask. What is this mask? This mask is dark field mask dark field mask all right.

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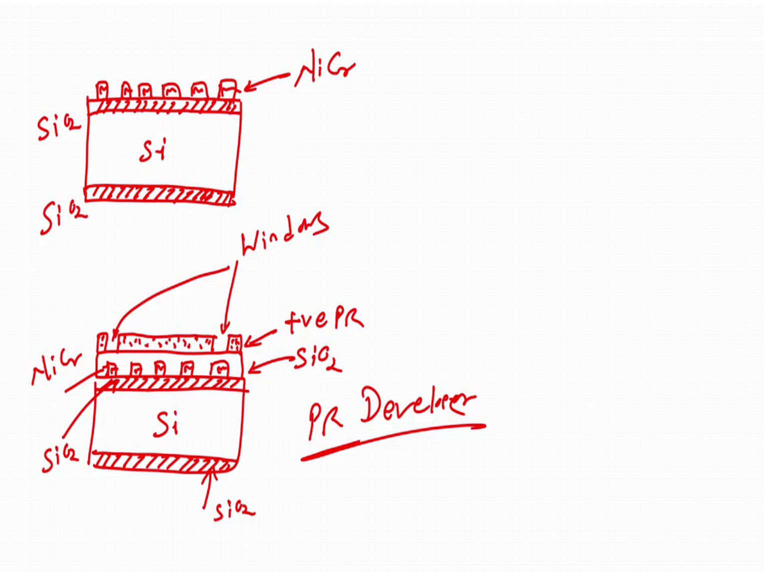

Next step is I will expose this wafer with UV light. After exposing, my next step would be, I have to develop the wafer for developing wafer we have to use photoresist developer right. So, if I dip this wafer in photoresist developer, after unloading the mask, and after UV exposure, what will I have? I will have my photoresist in the area which was not exposed by UV. And you can see here the windows for the contact to the micro heater are opened.

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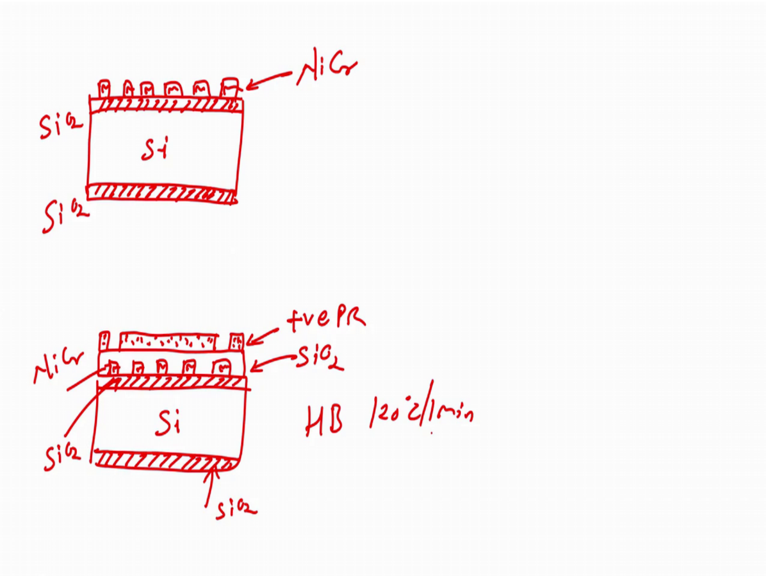

So, what is the next step? Once I have this, my next step is I will go for hard bake; hard bake is done at 120 degree for 1 minute correct ok.

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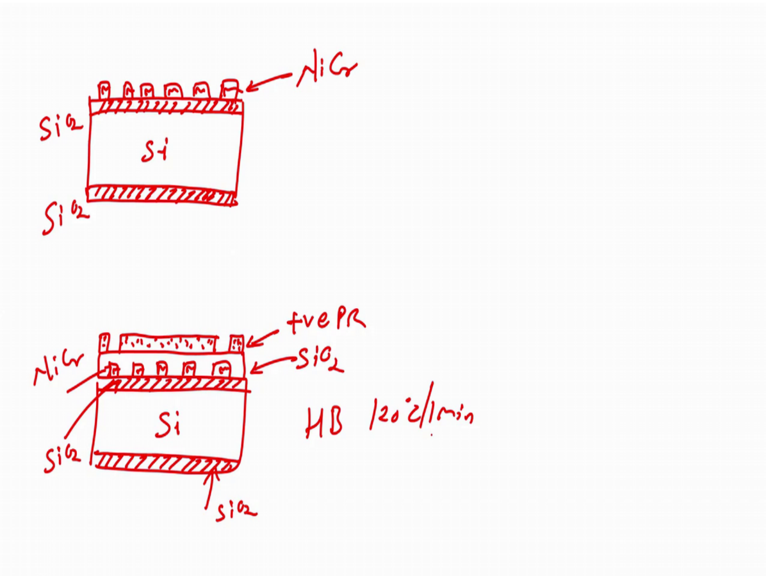

If I go for hard bake, the next step would be, I will dip the wafer in BHF. BHF stands for Buffer Hydrofluoric Acid. If I use BHF, what will happen, I will etch the silicon dioxide from the contact region from the contact region which is my heater contact, see there is no silicon dioxide you know there is no silicon dioxide in this particular area.

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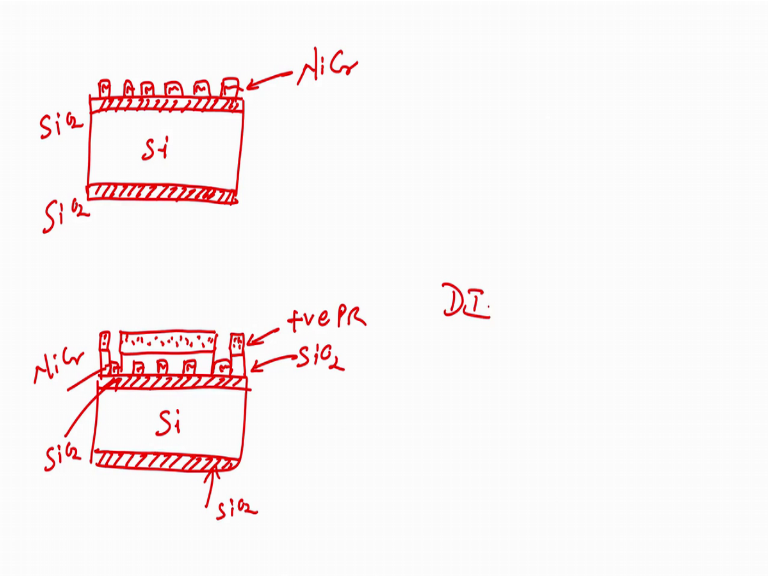

Now, I can access my heater right now I can access my heater. But, what I should do with this photoresist, I have to strip off the photoresist. So, after BHF after I rinse it, every step understand that you are there is a rinsing ok.

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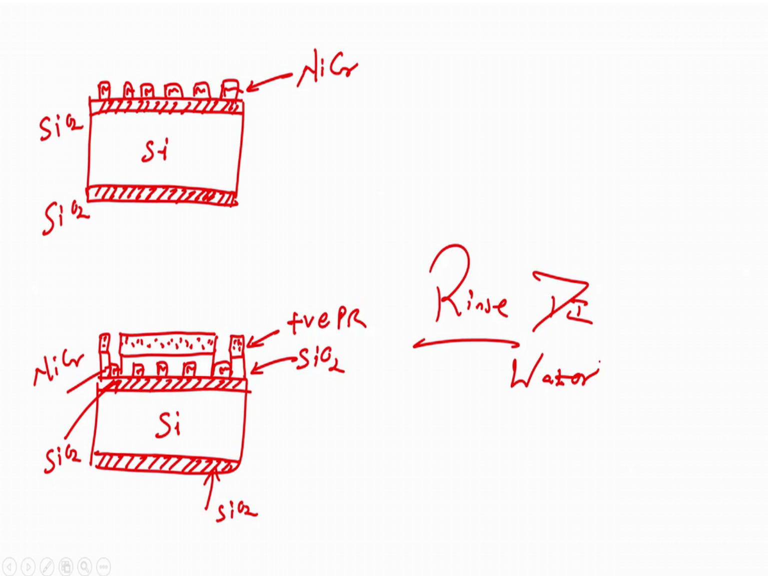

You have to washed wafer with DI water, you have to rinse the wafer rinse r i n s e wafer with DI water DI water. To every step, you have to go for rinsing with DI water.

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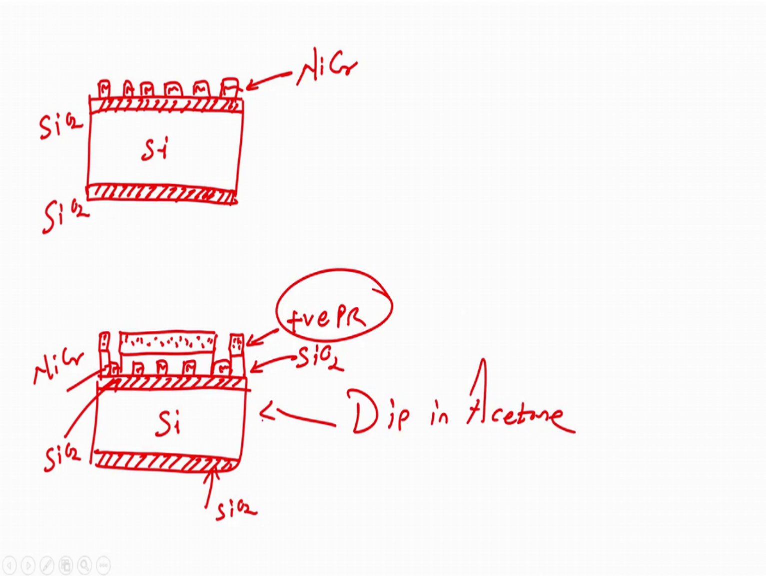

Now, after this we need to strip off the photoresistor, what we should do? We should dip this wafer in acetone. If I dip this wafer in acetone, my photoresist will be stripped off my photoresistor is stripped off, then what will I have, I will have a micro heater with silicon dioxide except on the contact pad right. What is the next step see, now what where are we if I show it to here this is silicon dioxide right, and this one is silicon dioxide, this is my heater. Now, on the silicon dioxide, what I have, I want to have sensing layer and electrodes.

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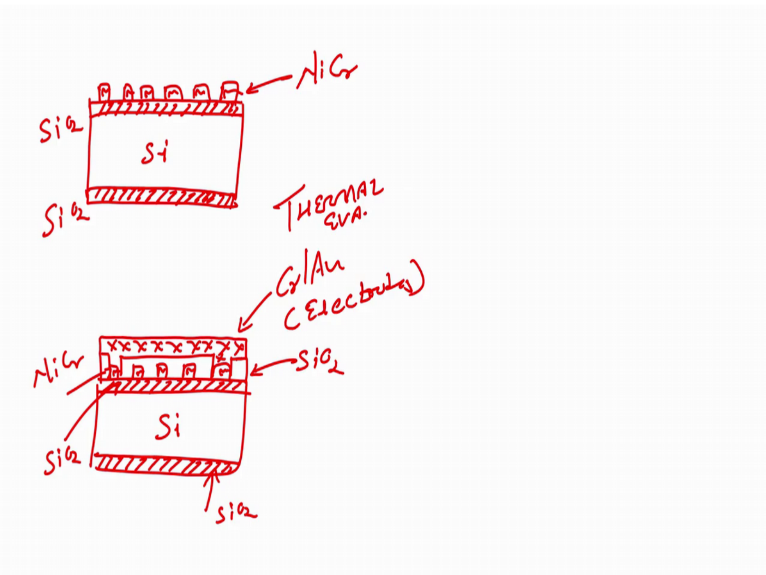

So, on this what I will do I will after this the next step would be I will deposit a metal. So, let me have pattern for metal as xx. This metal is for less this is chrome gold. This chrome gold is for electrodes. You can see right there are two heater context now I want to have electrodes. So, for electrodes, I will first deposit the metal using thermal evaporation, evaporation alright. After depositing metal the next step that I will perform is photolithography.

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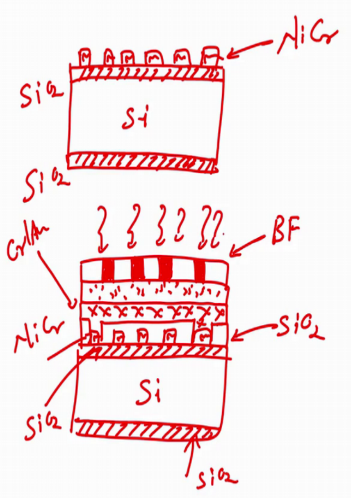

Now, you guys know right for photography what we need to do we have to deposit. So, this is my metal of course, chrome gold, and here is my photo resist right, positive soft bake, after photo resist spin coating we have to have soft bake. Soft bake is at 90 degree 1 minute followed by loading the mask, followed by loading the mask. And this mask is bright field mask this mask is bright field mask; after this, UV exposure. After UV exposure, we have to develop the wafer.

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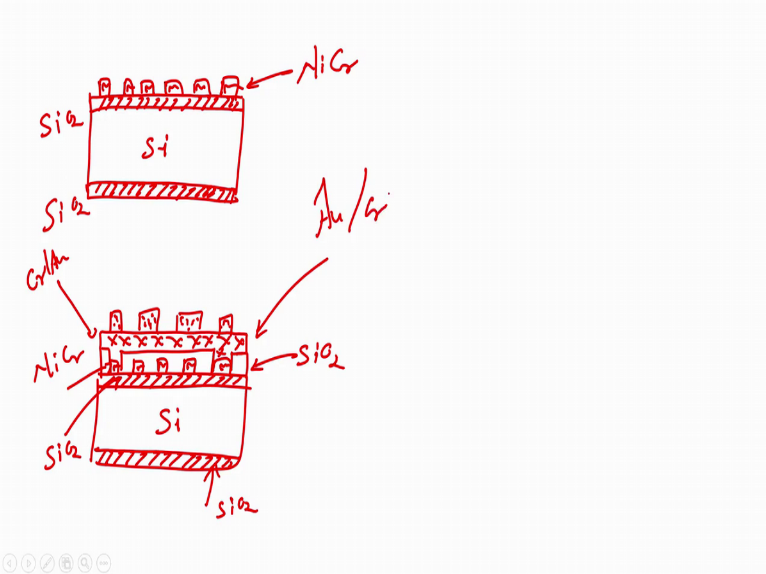

When you develop the wafer what will happen the photoresist which was not exposed a stronger photoresist is this area. And then right after this, if I develop if I etch this wafer etch chrome and gold by dipping the wafer in chrome etchant, first is gold etchant followed by chrome etchant, because chrome is at the bottom. So, first I will dip this wafer in gold etchant followed by chrome etchant. What will happen the photoresist, the area which is protected by photoresist will remain as it is in the area which is not protected by photoresist will get etched alright.

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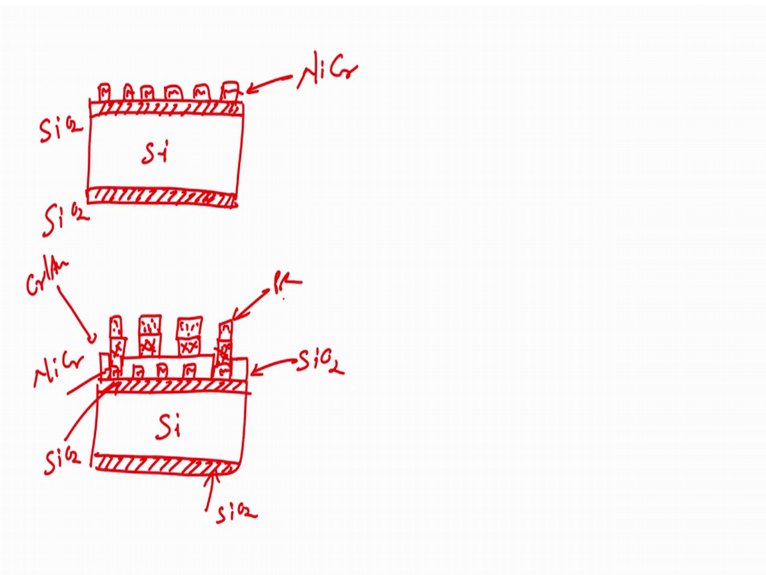

So, area which is protected by photoresist is stronger; area which is not protected by photoresist right you get etched. After this I will dip the wafer in acetone. Before that of course, after developing the photoresist, we have to do hard bake, do not forget that. So, after this, if I dip the wafer in acetone, I will strip off my photoresist. If I strip of my photoresist, what will I have, I will have chrome gold electrodes over nichrome heater and in between there is a insulating material which is Si O 2.

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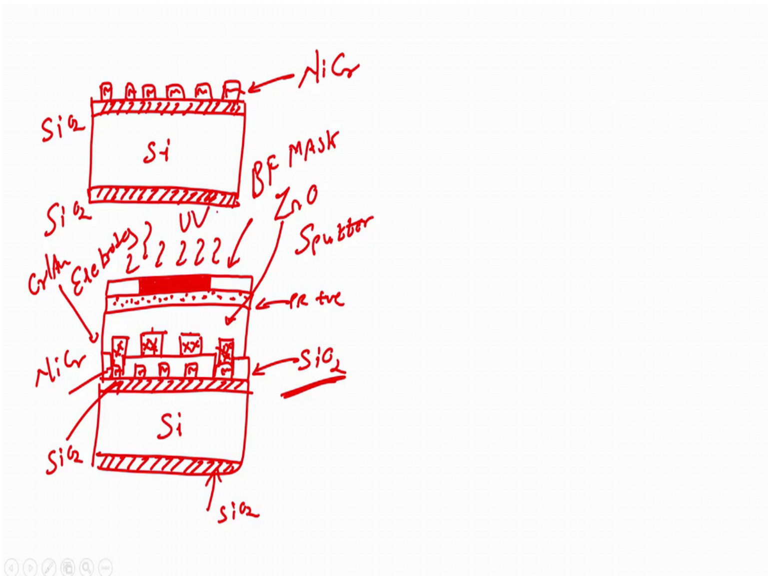

What is the next step, next step is I will deposit my sensing layer which is my metal oxide semiconductor, let us say Zn O sensing layer all right. How will I deposit my sensing layer, by sputtering? You take a zinc oxide target and then sputter it to form a film of zinc oxide, but do we require film oxides everywhere, no we only want film to be on this particular electrode, and the context should be open.

So, after this, the next step would be spin coat photo resist, perform soft bake, load mask, bright field mask, we only want to protect the photoresist over the electrodes and not on the contact area as we only want to protect the zinc oxide only on the context only on the electrodes and not on the contact area of the electrodes.

So, we have at this bright field mask right. This is zinc oxide is here all right, and this is our bright field mask. Next step is will expose with UV right. After this exposure, if I develop the wafer, what will happen, if I develop the wafer, then I will have my photoresist.

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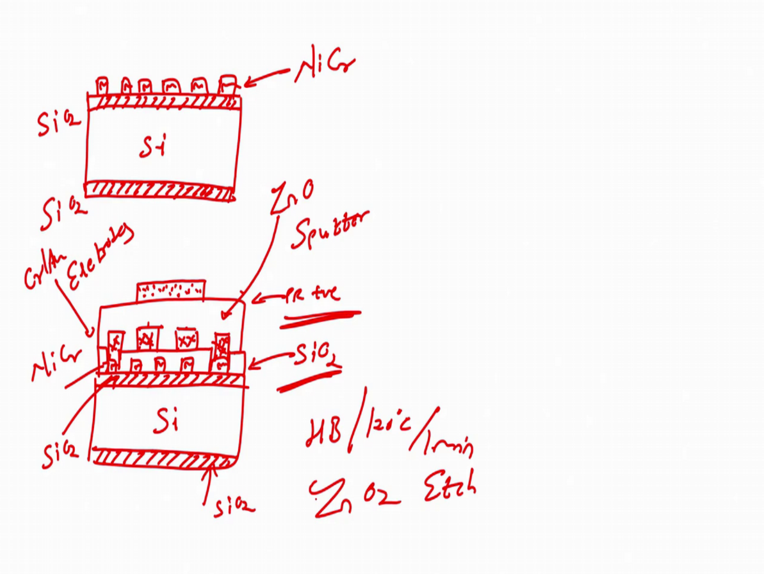

Only in this area because I used a bright field mask with a positive photoresist and that is why the unexposed region became stronger. After this I will go for hard bake 120, 1 minute, and then I will dip this wafer in zinc oxide etchant. I will dip this wafer in zinc oxide etchant.

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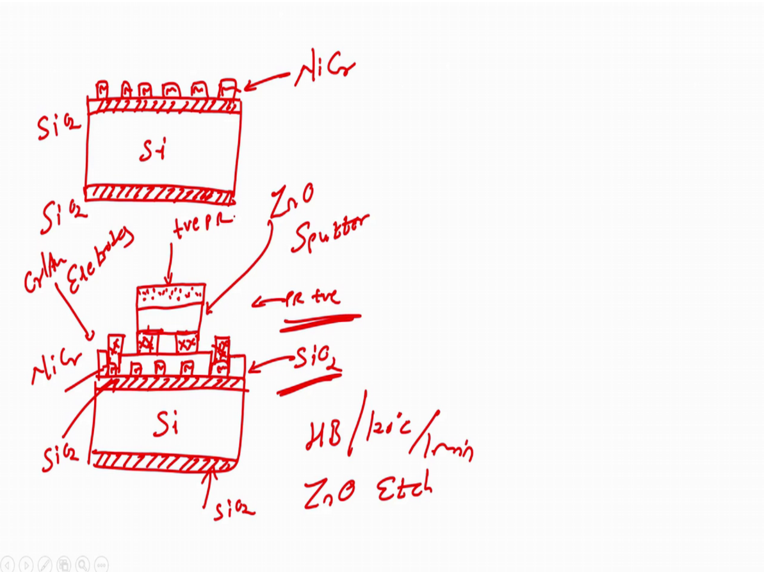

If I dip this wafer in zinc oxide ZnO ZnO etchant or ZnO2 Zno etchant, so, if I dip this wafer in zinc oxide etchant, what will happen I will have zinc oxide only on this area right only on this area. Why, because this area is protected by the photoresist correct. The last step is last step is I will dip this wafer in acetone.

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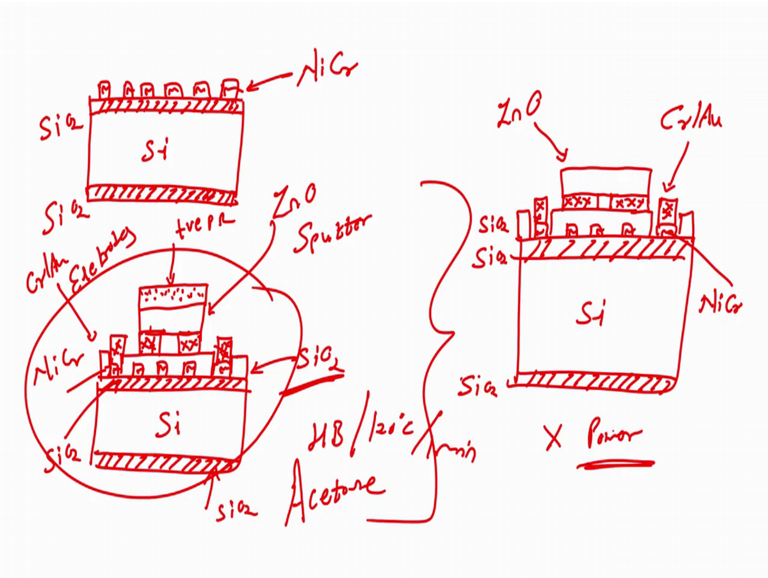

If I dip the wafer in acetone, what will I have? I will have my silicon oxide that is oxidized silicon wafer on which I will have my heater then I have insulating material right on which I will have my electrodes right, and my heater right. So, this is my Si O 2, this is Si O 2, this is Si O 2. This is nichrome. This is chrome gold. And this one is my zinc oxide right. If I dip this particular wafer in acetone, my photoresist will be stripped off. And I will have my zinc oxide material on chrome gold which are the electrodes.

So, how many contacts are there? I have four contacts two for the electrodes and two for the heater all right guys. So, this is the process flow for fabricating a sensor. Now, if you see, if I want to heat this particular silicon substrate, then I will require a some x amount of power right, x amount of power. If I want to reduce the power consumption for heating the silicon substrate, I can make a diaphragm what I can do? I can make a diaphragm.

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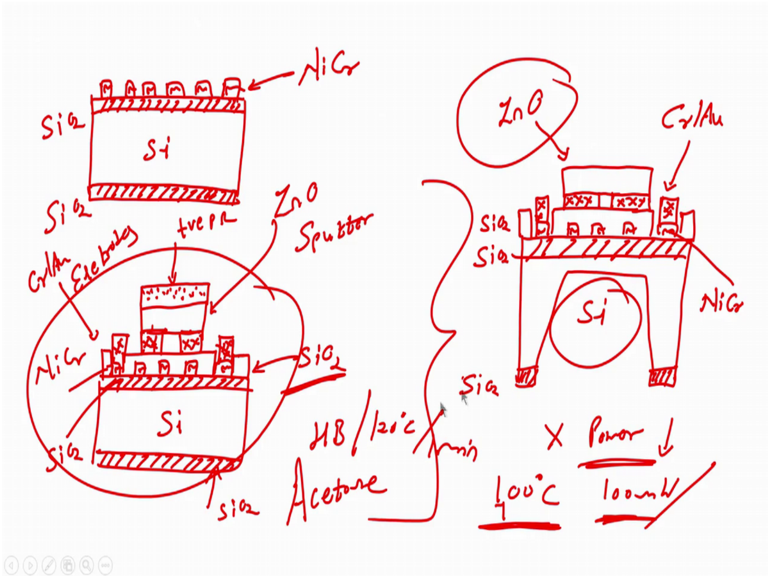

What does it mean if I etch the silicon substrate with bulk micromachining right, then now I have to heat sorry for the design like this all right, this is the kind of little bit better than earlier one ok. Now, I had to heat thin a thin layer of silicon and that is why I have my power to heat the semiconducting oxide will reduce. So, to obtain 100 degree centigrade or let us say 400 degree centigrade earlier was let us say 100 milli watt of power we required.

Now, for the same temperature if you want to reach 400 degree centigrade, I will require less amount of power because of my micromachining. So, this is a separate topic we do not get into this, by just giving an example that you can design a sensor and you can do this micro machining to fabricate the entire gas sensor, all right guys. So, what we have learned we have learned this is last slide. So, what we have learned, we have learned how we can design a gas sensor, we have learned how you can fabricate a gas sensor process flow, and how can we designs the signal conditioning circuit there can be attached to gas sensor so as to control the heating of the gas sensor.

Again this is a part of where we are understanding the heating of the gas sensor, but what about further changing the resistance to a readable format, so that we will be looking at or we have looked in the earlier slides or if not we will be looking in the next slides or next lecture in fact right. So, I hope that you understood the importance of sensors in particular you understand how you can design signal conditioning circuit for a particular sensor which is a gas sensor, and how you can fabricate a gas sensor using the process flow that I have shown you in this particular module.

Again to understand the process flow a lot of things that you need to understand for example, what kind of silicon substrate you have to use, what is the thickness of silicon dioxide, what kind of material you use, and what is the thickness of the sensing material, what is the thickness of electrodes, what is the thickness of heater which material to be used for heater, why only nichrome, why not platinum, why only chrome gold, why not other material like aluminum right. Then why zinc oxide, if I change the zinc oxide with thin oxide or indium oxide or indium tin oxide what will happen.

If I use tungsten oxide, what will happen these are all 2D materials? If I go for like so just a thin film right, if I instead of thin film use nano structures or nano wires will my sensitivity improve, lot of questions right. To give you answer quickly aluminum cannot be used because you get oxidized right, nichrome is easy to fabricate, platinum is costly. Chrome gold can be used because you know the conductivity of gold is very good compared to platinum, platinum is costlier chrome gold is cheaper.

Now, if you want to talk about the different materials, each material has its own characteristics for sensing particular VOC right. When we talked about zinc oxide or indium oxide or tin oxide tin oxide is extremely sensitive, indium oxide is selective, indium tin oxide we can use both the you know parameters of indium oxide and tin oxide. So, these are the some of the equations that you need to understand what is the thickness what. So, this is everything about the thickness change in that heater temperature everything you can do if you know how to perform a simulation using a software called COMSOL multiphysics all right.

So, we will see how a COMSOL multiphysics can be utilized to understand and to simulate your sensors in a next module right, till then you will take care. If any question, you ask me right or ask in a forum, we will be very happy to you know help you out. Again you understand this thing this is all thin film technology, where you require sophisticated equipment like clean room, inside the clean room for example, thermal evaporator, EBM evaporator, sputtering, photolithography, wet etching, dry etching right.

But if I want to use screen printing then I can do it anywhere in the with us with a little bit of facility. Because in screen printing what I want I just want let us say you have this particular screen right, you have a screen. Now, what I am doing is I am just cutting a sample from that particular screen all right one second just to give you an example just to give you an example. So, you guys understand how what is the advantage of screen printing and how you can utilize it for in your lab.

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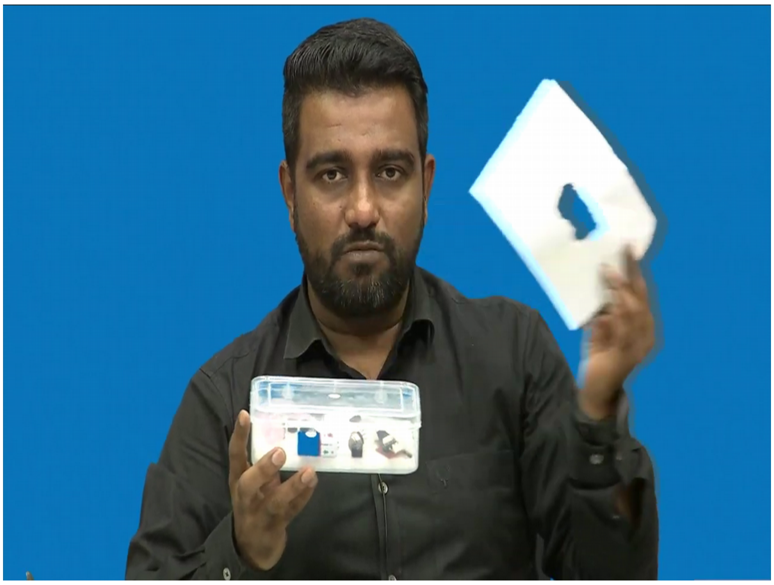

Now, this is a let us say a pattern, what will happen. If I load this screen on to a substrate let us say now I had loaded the screen onto a substrate right. If I depose if I have a material which is my sensing material and if I use a squeezy if I use a squeezy right, squeezy is like I understand that that there is a sensing material here. If I squeeze it like this on this particular substrate, what will happen that the material will pass through this particular whole, remaining area will not be affected.

So, when I remove this mask I will only have the central region where it will have sensing layer right. Now, if I heat this one at a particular temperature, I have my sensing layer ready. So, screen printing is very easy to up work on compared to thin film right, but there are advantages, disadvantages like in thin film you can have an extremely minute sensor in thick film it is a kind of difficult. Again once your sensor, you need to have a signal conditioning circuit all right.

Well, till then you take care, I will see you in the next class. Bye.