Introductory Neuroscience and Neuro Instrumentation
Indian Institute of Science, Bengaluru
Lecture No. 50
Photoresist (SU-8) and soft lithography

Hi, welcome to this particular module. In this module, we will look at the lithography section where we will talk about SU-8 as I have promised in the earlier module. And we will also look at the soft lithography. So, until now what we are looking at is how to perform a lithography using UV light and also we have seen the advantage of E-beam when you want to go to smaller resolution feature size.

Now we will talk about soft lithography which is little bit different than your hard lithography which is we use a wafer and then we use mask and so and so forth. In this case we will design a module or in other words we will design a mold and using the mold we will keep on creating a patterns using a single mold without multiple times using the UV exposure process, so what does it mean? And what kind of materials we can use for mould?

Now mold is a is a substrate that is patterned using the photolithography technique or any other technique. So, let us see the soft lithography but before we move towards the lithography, let us see one example of SU-8, an SU-8 will work similar to a negative photoresist. Now if you remember our positive photoresist when you the other unexposed region would get stronger and the exposed region would get weaker.

In a negative photoresist, the unexposed region would get weaker and the exposed region would get stronger. SU-8 works similar to negative photoresist that means that the unexposed region would be stronger and the exposed region would be weaker, with a one catch that generally when we use positive and negative photoresist, what are our steps? You take a substrate, clean the substrate whenever you clean the substrate that means that initially, a new wafer is there, let us take an example of silicon, what you do?

You take a silicon wafer, dip in HF or BHF to remove a native oxide that is because of the environment, then you rinse it with DI water, then you dry it with nitrogen then you pre-bake it at 120 so that the moisture is gone then you the spin coat positive or negative photoresist followed by soft bake, soft bake. Soft bake is done at 90 degree centigrade one minute on hot plate. Followed by loading a mask aligning the mask and UV exposure.

So, when you load the mask as you have seen in earlier videos where there is a UV lithography systems or make liner systems were shown you will be able to see that there is a separation when you align the mask with respect to the wafer. You have two options either you align the mask by moving the mask either in x or y or z, x is generally like, let x and then y and then theta, theta is rotation. So, you have 3 moment, either you do that with mask or you do that with wafer.

So generally what we prefer is we do that with a wafer and the mask is an is straight is in fixed position that is a right word. So what we do is, there is a separation between two when you align it, once you align then there is a hard contact when there is a hard contact then you expose the wafer using the UV lithography or UV light. After UV exposure the next step would be developer and after developer the next step would be hard bake.

Now you remember soft bake, expose, develop, hard bake. But SU-8 is slightly different it works as negative photoresist but in the SU-8 you have to go for soft bake, align and exposure, post-exposure bake or hard bake and then develop, you got it. So. one step is reverse in positive and negative photoresist soft bake, align and exposure, developer, hard bake. In SU-8, soft bake, align and exposure, hard bake then developer.

So just last two process are little bit changed and that is the that is the process flow or recipe to pattern SU-8, we will see an example I will take an example so that you understand. An SU-8 can also be used to create the mold, so how it is done let us see.

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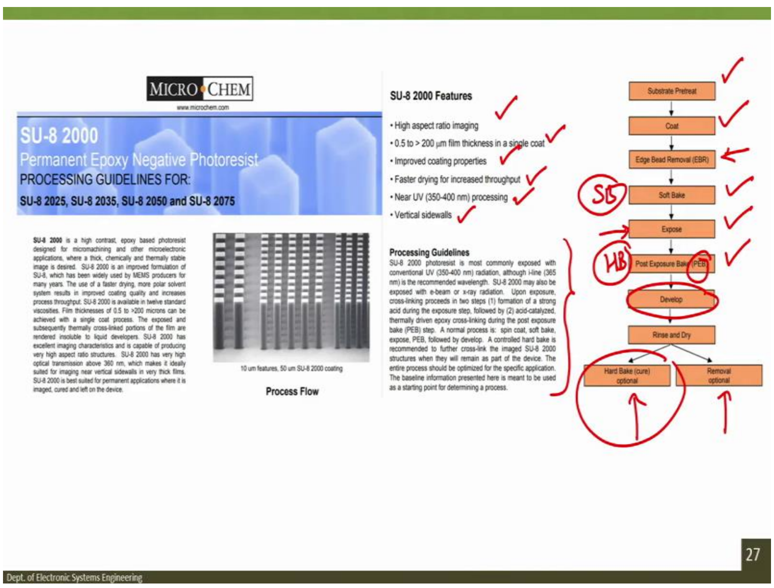

So, if you see the slide as you generally we buy through a company called Micro Chem and SU-8 has a different viscosity and depending on the thickness of SU-8, you can select different SU-8 photoresist maybe 2025, 2035, 2050, 2075 depending on how thick your feature size you require. This particular image shows 10 micron features 50 micron features using SU-8 2000 coating. Also, is a high contrast epoxy bed photoresist designed for micromachining and microelectronic applications where a thick chemically and thermally stable.

So, it is not just a chemically stable SU-8 material, but also A thermally stable. Now, it is generally exclusively used in mems-based processes for many years and the film thickness in su 8 can vary from 0.5 micron all the way till 200 microns and more and with a single coat process. So, the process the features of SU-8 are, it has a high aspect ratio imaging 0.5 to 2 greater than 200 micron film thickness in a single coat improved coating properties, faster drying for increased throughput, near UV that is 350 to 400 nanometer processing and finally there are vertical side walls which we can get using SU-8.

So, the process guidelines that means how can we fabricate SU-8 is shown in this particular process flow, the first is you have to substrate preheat, then you can coat with SU-8, then you have to remove the edges of the wafer see when you coat it, there will be SU-8 somewhere in the edge so this edge removal process is there or edge bit removal process is there in some cases so we go for edge bit removal.

Next is soft bake, then align and expose, then post exposure bake or hard bake you see here, so soft bake, soft bake, align and expose, then hard bake and then you have develop. After develop you can rinse and dry you can go for further curing option of another hard bake or you can use a removal option. So, this is the same thing which is right written over here, if you read it it is saying that SU-8 2000 photoresist is most commonly exposed with conventional UV radiation.

Although eye line is recommended wavelength, SU-8 2000 may also be exposed with E-Beam or x-ray radiation, that means either it can be used in E-Beam lithography or x-ray radiation upon exposure cross thinking process in two steps. For first is the formation of a strong acid during exposure step and second is acid is catalyse thermally driven epoxy cross linking during post exposure bake.

Finally, a normal process is a spin coat soft bed exposure pose exposure way followed by developed, a control hard bake is recommended which is here at the end so there are two things because to avoid confusion the hard bake is done here and instead of hard hardback here they have written PEB which is post exposure bake, soft make, exposed, post exposure bake, the temperature will vary depending on the thickness of the photoresist.

In this case it is not that 90 degree should be at soft bake and 120 degree should be hard bake, no. This is not a real case in when you use SU-8, depending on the viscosity of the SU-8 and the type of SU-8 it can be 2025, it can be 2075, the soft bake and the post exposure bake temperature will change and correspondingly the time also would change. So, this is what is written and the entire process should be optimized for the specific application. The base the information presented here is meant to be used as starting point for determining the process.

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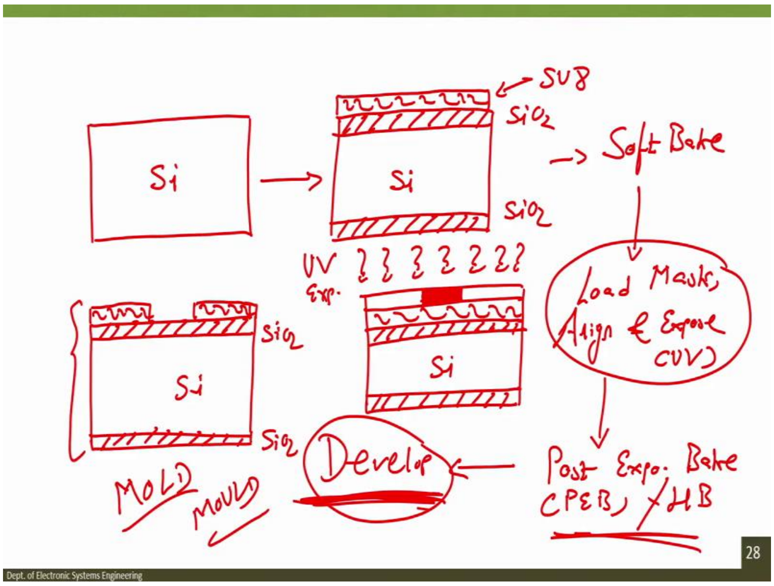

So, let us take an example of an SU-8 patterning, SU-8 patterning. So, we take a silicon as a base material, next is we grow silicon dioxide, how we grow silicon dioxide? If you remember we have learned thermal oxidation technique, it can be wet oxidation, it can be dry oxidation. Next step would be you spin coat SU-8, so let us say SU-8 we are representing like this is your SU-8, next step would be soft bake, next step would be load mask, load mask, align and expose, expose again is UV.

Next step, post exposure bake, post exposure bake, which is also called PEB or you can say hard bake. Next step is developing, so here let us have a mask so to help this, this step load, align and expose you have a mask, silicon, Sio2 SU-8 and our mask let us say there is a bright film mask and some pattern is there on this bright field mask. So, after loading the mask and aligning it, we will go for uv exposure, after uv exposure we unload the mass and go for post exposure bake then we develop the wafer, when you develop the wafer what will happen?

Since SU-8 act as a negative photoresist, Sio2 silicon Sio2 now what what I said, SU-8 act as a negative photoresist, the unexposed region would be weaker and the exposed region would be stronger. So, the unexposed region you can see in the schematic is weaker you see here, it is developed after developing step. After you perform loading and mask and align and exposure after you go for post exposure bake and when you dip the wafer in developer, then what will happen?

The SU-8 developer will develop the area which is not exposed, that means the area which is not exposed gets weaker, the area which is exposed gets stronger. And then you can go for another hard bake at a high temperature and you will have this particular mold I will call this as a mold now there is a reason, we write in different way the mold or mould, it does not matter. So, you understand that there is a mold with this particular pattern. Now, let me explain a slightly different way of creating similar design in silicon wafer.

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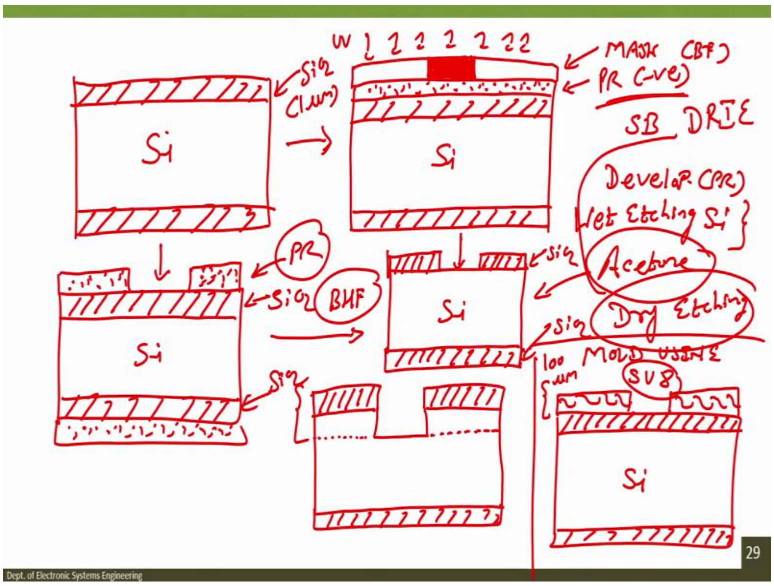

In silicon if you want to have this kind of design, so let us take an example here that we have a mold using SU-8 which will look like this, you have oxidized silicon and you have SU-8 mold which we have just seen here in the previous slide and this is our silicon dioxide is also silicon dioxide this is silicon, this is our mold using SU-8.

Now let us see mold using silicon. So, we have silicon wafer, you grow silicon dioxide, next step you spin code photoresist, spin coat photoresist. Let us say we have to create a silicon wafer that looks like this. Now, suppose SU-8 is 100 microns 100 microns and our Sio2 is just 1 micron, so we cannot make wall of Sio2 we cannot have this as an Sio2, what we need to do is we need to etch this further this guy further 99 microns, then only we will have similar to SU-8, so we will create something like this.

Now together this plus the Sio2 this plus this will be 100 which is similar to this 100 micron here in SU-8. So, we have to create this design and for that or we can we have to create this pattern for that what I will do is I will take a negative photoresist, so this is a photoresist which is negative photoresist, spin coat on the oxidized silicon substrate then load a mask, this is my mask and is a bright field mask after that you will expose the wafer with UV light, then you unload the mask then perform.

So, after you of course after positive photoresist you have to go for soft bake, then you load the mask, expose it, unload the mask, then go for developer, which developer? Photoresist developer in this case negative photoresist developer. So, when you develop the photoresist, what you will have? You will have a wafer with photoresist in this area and the unexposed region will become weaker, why? Because this is a negative photoresist that we have used.

Now if I dip this wafer in bhf, what will happen? I will have, let me draw like this, if I did this wafer in BHF, what I will have? Sio2 will be etched on backside also I can protect the Sio2 on the backside by coating photoresist, so let us assume that Sio2 on the backside is protected only front side we are etching so if I dip the wafer in BHF the Sio2 that is exposed in this case here we will protect with let's say photoresist or any other thing maybe physical protection is also possible. So, what we have the Sio2 which was not protected by the photoresist got etched when we dip the wafer in the BHF.

Now if I dip this further, this wafer in acetone what will happen the photoresist on the top as you can see in the slide if I dip the reference acetone, the photoresist on the from the top of the Sio2 will be etched when I dip the wafer in acetone. Now the next step would be that you perform wet etching, wet etching of what? Wet etching of silicon, so if I perform wet etching of silicon that means silicon will get etch, Sio2 will not get affected, Sio2 will not get affected only silicon will get etch when I perform wet etching.

I can also perform drie etching, now this is not a spelling mistake, Drei stands for deep reactive ion etching. I have not written d r y its called dry etching dry etching but the process is called this dry etching process is called drei which is deep reactive ion etching. So, if I perform deep reactor ion etching or I go for wet etching of silicon which can be for using the potassium hydroxide which is Koh or tmah tetramethylamonimide hydroxide, then I can perform the silicon etching.

Now this both drei etching, as well as wet etching, will not affect your silicon dioxide because if you again remember silicon dioxide would work as a mask when you are etching this silicon material.

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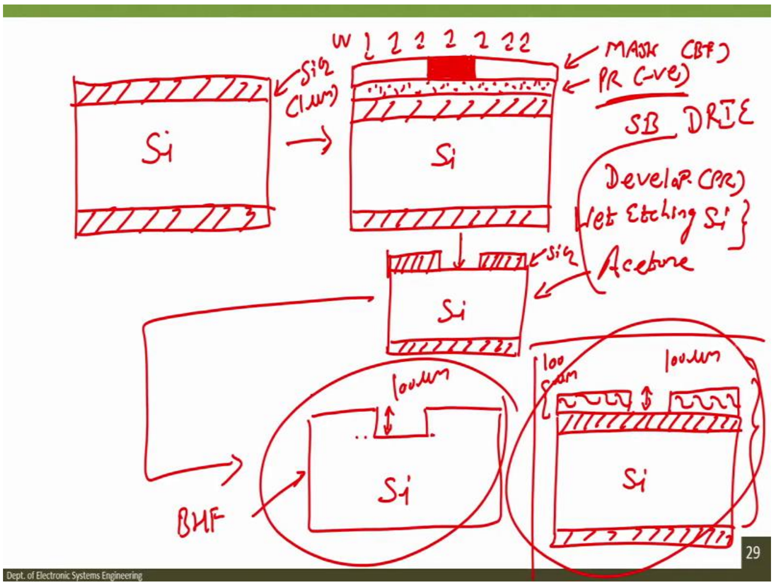

So, if you perform the silicon etching what you will have, I will just remove the some of the text from here, so it becomes easier so if I perform the silicon etching, what I will have? I will have let me just remove this one, so if I perform wet etching or dry etching by dipping the wafer in Koh or tmh then I will reach this particular pattern. Now in case if I remove the silicon dioxide, that means after reaching this pattern if I dip this wafer in BHF, what will happen the silicon dioxide will get etch and I will be having silicon vapor like this, is it similar to this pattern?

Yes, why? Because the thickness or the pit here see in this case also the SU-8 this pit is 100 microns, here silicon pit is also 100 microns because I have etch silicon for 100 microns. So, now this is my mold and SU-8 is also my mold.

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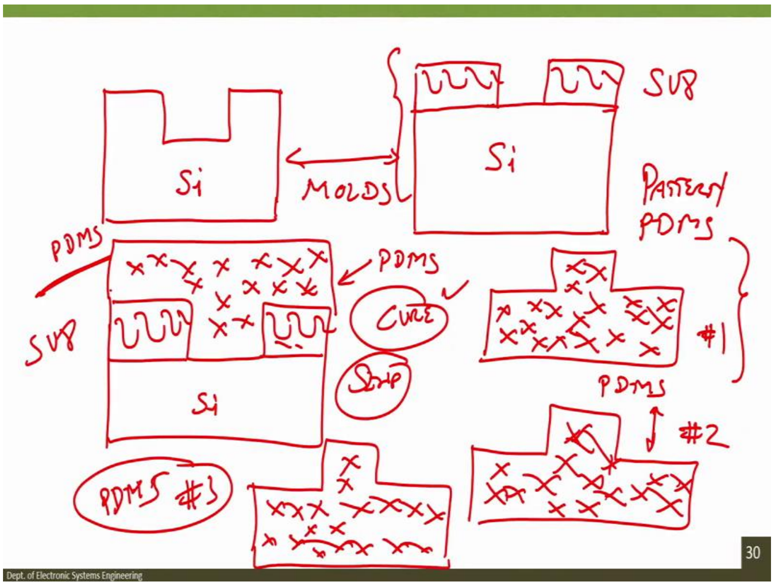

So, what we see here you have two molds, one is made out of silicon and one is made out of SU-8, the silicon mold will look like this, this is silicon and the SU-8 mold, SU-8 mold will look like this, this is SU-8 and this is your silicon mold this both are what, both are called molds. Now let us see the advantage of your soft lithography advantage of soft lithography we will take this mold and we will spin coat PDMS on this silicon mold, pin coat PDMS PDMS it is also a polymer soft polymer, so what I have done?

I have spin code or spin-coated PDMS and let us have PDMS represented by these dots or in fact just to avoid any confusion we will have PDMS represented by a symbol x or an alphabet x. What is this? This is my PDMS. Now after I spin coat PDMS I will cure it and I will strip it, when I strip it, how it will look like? It will look like this, of course not that big but this is my PDMS. So, when I strip it I cannot see I will get back my silicon mold. Now in the next step I will another cure or spin coat another PDMS once again cure it and strip it, when I strip it I will get another pattern of PDMS this is first, this is second and so on I can repeat this process as long as my mold is intact.

So, what you see is that there is a pattern pdms every time when I use this silicon mold, that means I am performing some kind of patterning of PDMS without using any kind of UV light that means this is called soft lithography, soft litho. Now let us see one more thing if I do not use silicon and if I use SU-8, what will happen? In case of SU-8, this is SU-8 and this is my silicon this is SU-8 in this case I will load or spin coat PDMS cure it and strip it, what will I have? I have PDMS number 3. So, either using silicon or using SU-8 I can pattern my PDMS, that means both of silicon and SU-8 can help me to get the mold.

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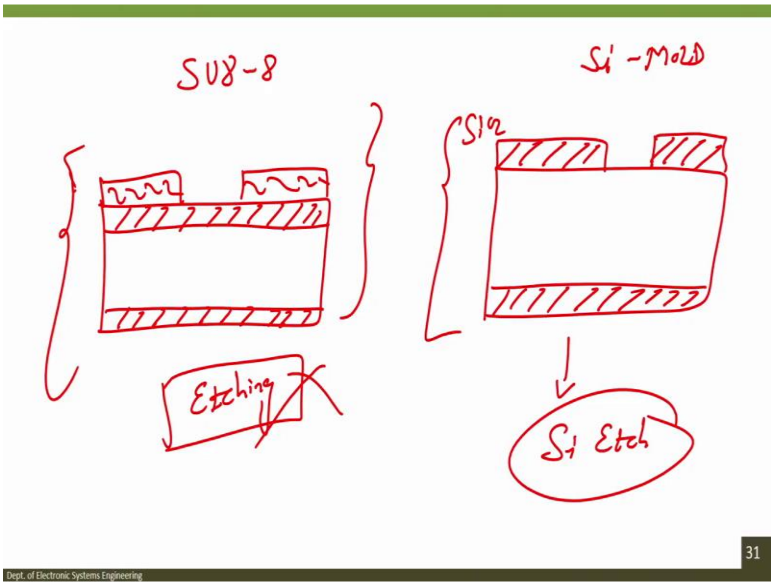

Now what is the advantage of SU-8, in this case, is that I do not have to see, in the advantage of SU-8 su 8 mold versus silicon mold, what is the advantage of SU-8? That once I spin coat on the oxidized silicon substrate and I perform lithography I will have my SU-8 pattern as shown earlier I do not have to go for any kind of etching I just have to go for the developing step. In silicon you have to go for first you have to create a silicon dioxide window in silicon dioxide there is using the lithography step which is also done here, this is your Sio2 and next is you have to also perform silicon etch.

In this case you do not have to perform any etching just SU-8 developer developing SU-8 will get you the mold, so the advantage of SU-8 mould over silicon mold is that we have a lesser number of steps compared to creating a mold in the silicon wafer.

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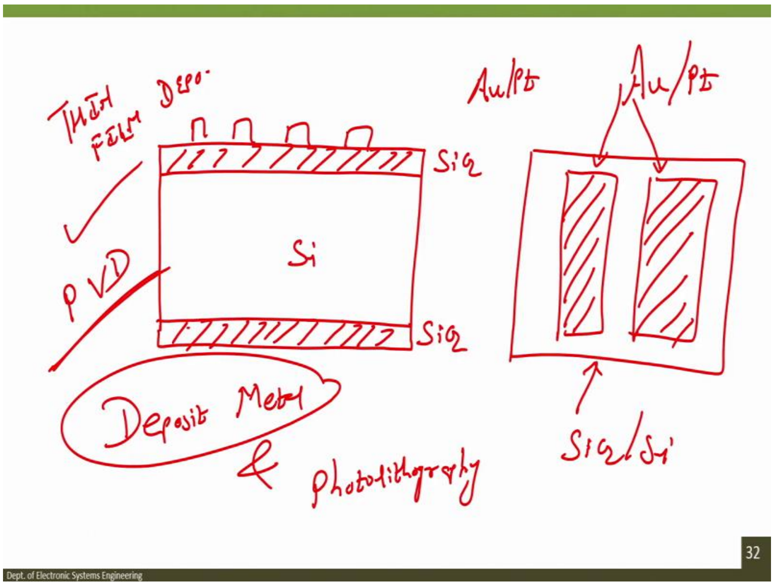

Now, we will see that let us have a metal, metal so I will just draw the top view and the side view, top view my metal electrodes will look like this, these are my metal electrodes and this is my silicon dioxide on silicon, what are these metals? Metal is gold or platinum-like gold or platinum these both electrodes. So, on this of course silicon dioxide and silicon that means you have silicon dioxide these are cross-sectional v order.

So, what we have here are gold or platinum electrodes on Sio2 gold or platinum electrodes on oxidized silicon substrate. So, the point is to pattern this gold or platinum electrodes on oxidized silicon substrate, what we have to perform? We have to first deposit metal and then perform photolithography, photolithography and I will explain you how to create this particular pattern in one of the modules.

But my first point is before you pattern this Au/Pt like this you have to deposit Au/Pt which is a Au/Pt let us say it is shown by this symbol, either gold or platinum you are depositing it and then you perform the photolithography where you spin code the photoresist load the mask expose the wafer and then develop the photoresist then go for hard bake and then you etch gold and platinum to get our final pattern which is the one that I have drawn earlier like this.

So, how you will deposit this metal? And for depositing metal there is a technique called thin film deposition, thin film deposition or physical vapor deposition techniques thin film deposition techniques or physical vapor deposition techniques. So, let us see in a next module how this thin film deposition techniques are used for depositing not only metal but also semiconductor and insulator and then we will take an example of how to create an electrode that you can possibly use for acquiring signals either it is EMG or it is ECG or it is EEG it is just a metal patch that we will be designing and then we can modify that metal patch to take the signals from the body.

So, you I hope you understood the importance of SU-8 I also hope that you understood how to create molds and how to perform soft lithography, now the application of soft lithography are mostly in microfluidics which is not part of this course, so we will not go in discussion or will not go and understand the details about the microfluidics but the point of me showing you the importance of SU-8 compared to silicon is that with SU-8 you reduce one mask process.

Of course there are some pros and cons because the SU-8 the wall thickness or the wall roughness would be not as great as the silicon wall but nevertheless, the point is that we want to pattern a material we need to know how to deposit a material until you deposit you cannot know, it is not just silicon dioxide like thermal oxidation where we go for thermal oxidation the Sio2 is grown on silicon either using bed etching or using dry etching.

In this case how about you want to grow a metal gold chrome aluminum or deposit, chrome gold chrome, aluminium, platinum, nickel, nichrome and how you can deposit different insulating material let us say you have an indium tin oxide or zinc oxide or tin oxide then how can you deposit different insulating materials silicon nitride, silicon dioxide and so and so forth.

So, let us see deposition techniques that will help you to understand if you have a substrate and you oxidize this substrate over that how you can deposit metal after you have metal deposited on the substrate then you perform the lithography to achieve the pattern that you require for a certain application, in this case it can be EEG in other case it can be EMG, in other case it can be ECG and so on and so forth.