Sensors and Actuators
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Lecture - 08
Microfabrication Basics

Hi, welcome to this particular module in the last module. If you remember what we have seen is components in microelectronics on MEMS based technology where we were talking about micro sensors microelectronics and then micro actuators and microstructures; so, how they are interrelated right.

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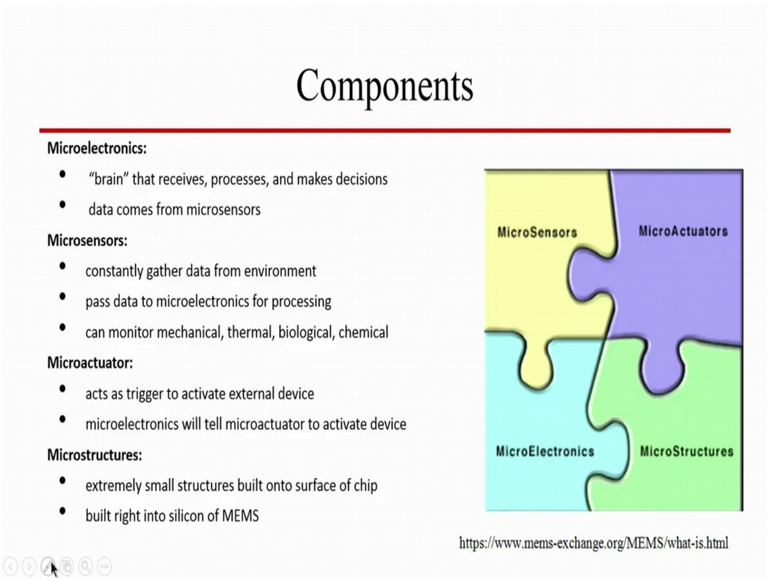

Say if you want to just quickly recall; if you see the slide we talked about microelectronics, then that is considered as a brain that receives processes and makes the decision and data comes from the microsensors. So, when the data comes from the microsensors, it is processed through your microelectronic circuits right.

So, there are several domains in which people work and you know work on research ideas and these are four domains within the MEMS and each one has a significant amount of research in world. Microelectronics is where you design the circuits using carens right and further you have to fabricate it using the foundry and microsensors is where you actually fabricate sensors.

So, our part here is to understand about microsensors and microactuators. Now when you talk about microsensors the concept or the role of the microsensor is to constantly get the data from the environment. Suppose it is gas sensor, it will constantly get the data about the gas from the environment. If it is a pressure sensor and if there is a uniform pressure applied whether the pressure is increasing or decreasing, it will constantly measure the pressure.

So, anything that is sensor is meant for sensing, it should constantly gather the data and send it to the processing unit and your processing unit is a microelectronic circuit. Now the road is to pass the data to microelectronics. So, first is constantly gather data from environment, second is pass data to microelectronics for processing and third one is that it can measure and monitor mechanical thermal biological chemical and lot more right. So, this is the role of the microsensors for monitoring several you know data from the environment. And finally, when you talk about microactuators, then it acts as a trigger to activate external device microelectronics will tell microactuators to when to activate.

So, first this sensor the data goes from the microsensors to microelectronics from microelectronics. So, microelectronics will send the data to the microactuator to actuate alright. So, and then finally, you have a microstructures this microstructures are extremely small structures built onto surface of chip and built right into silicon of MEMs; will be looking at the microstructures in a while.

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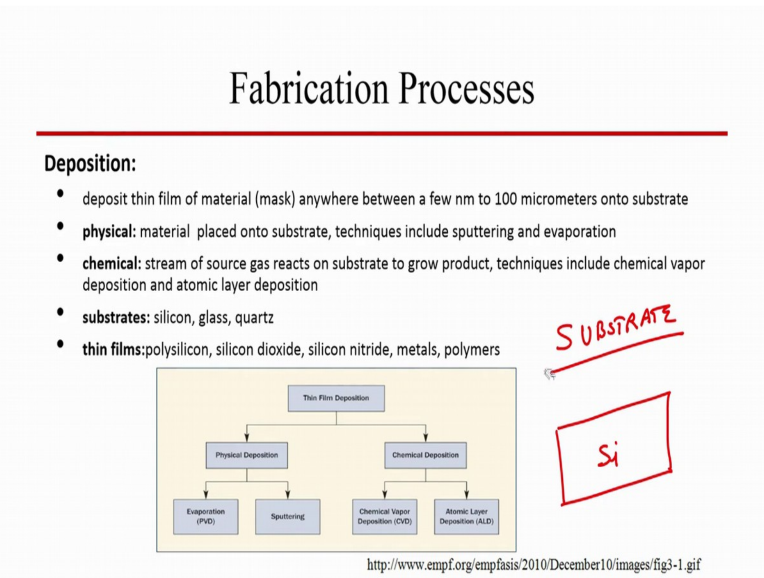

So, when you talk about fabrication process alright and that today we will learn very important process call photolithography. So, in the fabrication process, the first step is that you have to deposit a film right. So, I if you remember, we have discussed about substrate. What is substrate? Anything on which we are going to fabricate the device right. It can be silicon, it can be germanium, it can be glass, it can be metal anything. So, substrate is a material on which we are going to design and fabricate the sensor or actuator or any other device.

Now through let say you want to fabricate a heater right; so, you have a silicon vapor if I have a silicon vapor. Can I deposit another material silicon vapor metal? No because silicon is semiconductor. So, I had to have a insulating layer.

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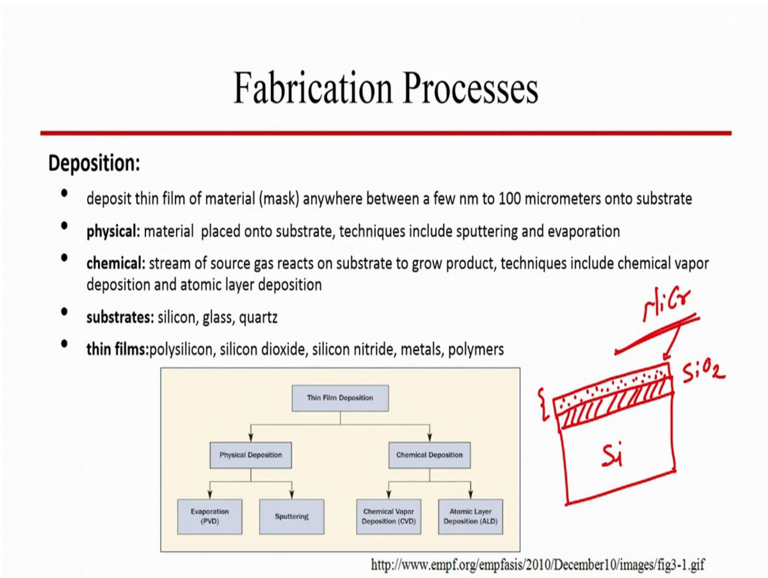

So, if in that case we have a insulating layer this insulating layer is SiO 2 right and then on that we will deposit a metal. This metal is your nichrome right; nichrome is a material that used for fabricating the heater. Now how to deposit this metal for fabricating our heater? So, there where the deposition technique comes into play; in deposition deposit thin film of material anywhere between few nanometer to 100 micrometers onto a substrate. If I deposit a film the thickness can be from few nanometer to 100 micrometers depending on what kind of technology you are using to deposit the material. Then you have two kinds of deposition; the first one is physical deposition and second one is chemical deposition.

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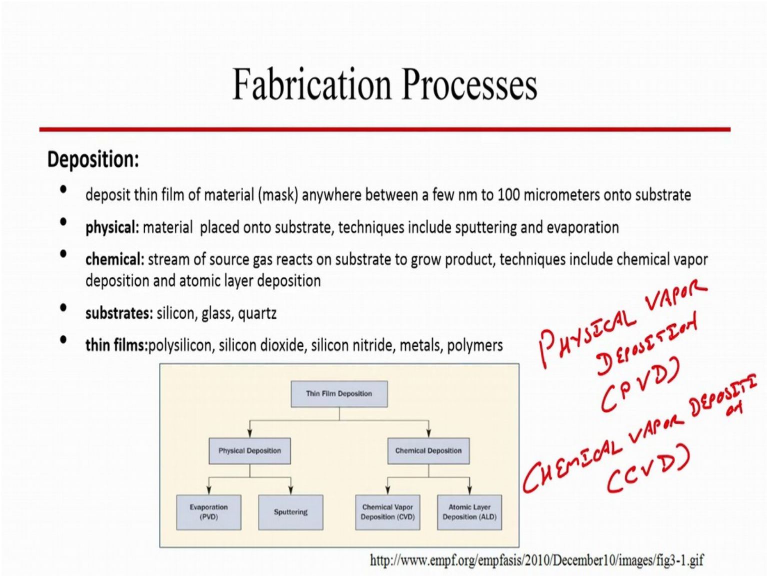

So, in MEMS we call this as physical vapor deposition and chemical vapor deposition l Physical Vapor Deposition also called PVD and chemical vapor deposition also known as CVD alright. Two techniques to deposit a material on to the substrate physical vapor deposition and chemical vapor deposition. In physical vapor deposition, the material is placed on to substrate techniques include sputtering and evaporation. We will see both the techniques.

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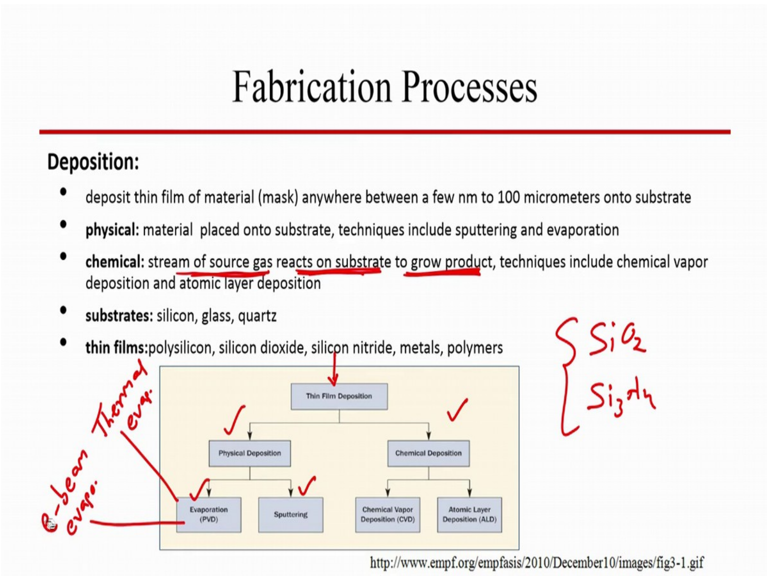

In evaporation further if you want to; so, if you see the film deposition in particularly thin film deposition, then you have physical vapor deposition and then you have chemical vapor deposition right.

In physical vapor deposition or physical deposition, you have evaporation and then you have sputtering correct. Now in evaporation further you want to understand, then there is some there is a process called e-beam evaporation and another technique is called thermal evaporation. One technique is e electron beam evaporation the second technique is called thermal evaporation alright. And a sputtering is a mechanical way of dislodging the atoms and depositing a film. We will discuss about sputtering e beam and thermal in detail in few modules.

So, the second process is your chemical vapor deposition in chemical vapor deposition, what happens? If you see the slide the stream of source gas reacts on substrate; stream of source gas reacts on a substrate to grow the product. For example, if you want to grow silicon dioxide right or you want to grow silicon nitride right, then you can use the CVD technique; in technique includes chemical vapor deposition and atomic layer deposition. So, in chemical depositions, you have Chemical Vapor Deposition call CVD and Atomic Layer Deposition call ALD.

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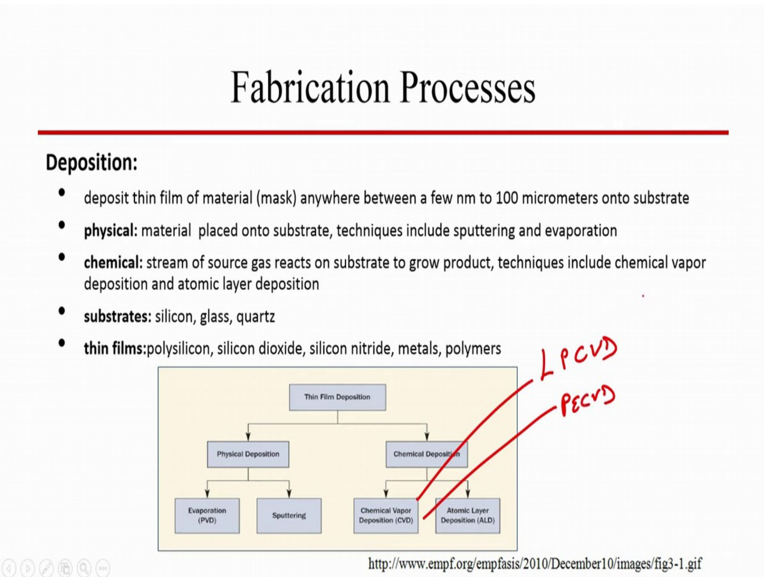

And in CVD further if you want to understand, then there is LPCVD then there is PECVD right. LPCVD PECVD, Low Pressure Chemical Vapor Deposition, Plasma Enhance Chemical Vapor Deposition.

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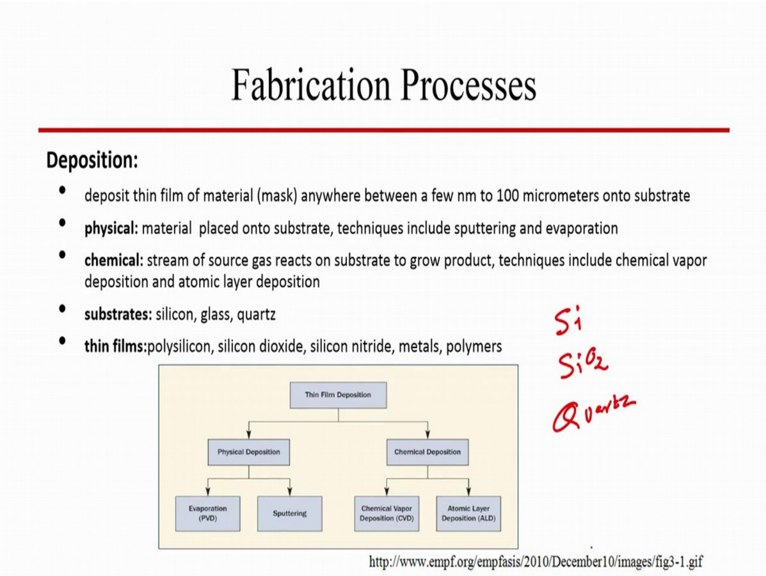

If you want to understand what are the substrate that we generally use in microsensors ah, then these are the substrates. The first one is silicon, second is your glass, glass is also SiO 2, third one is quartz and then many more alright, but most frequently use are silicon, glass and quartz alumina is also used. So, thin films examples are polysilicon, silicon dioxide, silicon nitride, metals and polymers right even deposit thin film of polymer; let say p dot p s s; p dot p s s is a conducting polymer.

So, if I want to deposit the thin film of conducting polymer, I can uses CVD technique. If I want to deposit metal chrome gold at, then I can use a PVD technique; you can use e beam evaporation, you can use sputtering. If I want to deposit silicon dioxide, I can use sputtering or I can use PECVD or LPCVD. If I want to the deposit polysilicon again, I can use sputtering.

So, depending on what kind of film you want to deposit and the melting point of the material is very important because that we will see why it is important. Particularly understand in a two sentence or two lines, I am just showing you to a example assume that there is a film on this particular material alright and you have to deposit a film on the substrate this is a source and there is a some metal on this source.

So, let us put this key is a metal this is a metal ok. Now you want to deposit this metal on my substrate, my substrate is let say metal got metal fell down right.

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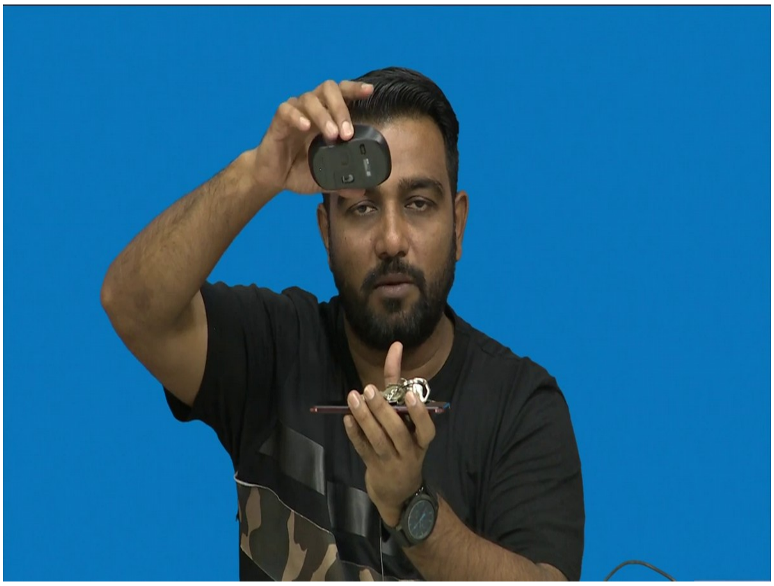

So, it will does not happen when you actually deposit a film it will stay there because there is a boat and then let say this is a substrate on which you want to deposit a film. Now for depositing this metal on the substrate, how can you deposit? Here to melt this metal is not it. So, I had to melt this metal right such that it will evaporate from this source and we will get deposited on the substrate; substrate on the bottom right. Here we do have a deposition of this particular metal.

So, to do that what I have to do I have to melt this for melting this source the material on the source, what we have to do? We have to heat this metal; heat this metal beyond its melting point beyond its melting point. When you heat the metal beyond its melting point, what will happen? The metal will get evaporated. It will it will converted into vapor and it will be deposited on to the substrate. So, to do that what you have understood that the melting point of the source the material that we are using on which you have the metal cap right.

So, this melting point of the source should be extremely high compared to the melting point of the material that you are going to deposit, is not it. The melting point of this metal and the melting point of the source that what we are talking about; the source is where you have to holding it ok. I am talking about this particular let say right, now I am holding a mobile, but you assume that this mobile is a metal boat on which we are loading the material.

Now, I want to evaporate this material. So, I have to heat this. So, the melting point of this material should be extremely high. So, then when this gets into molter form, this should not get affected right. So, in that case if I have melt it very high temperature, it will be evaporated and deposited on the substrate which is at the top of the vacuum chamber. We will talk about why the car vacuum and other things in the other module.

So, the point is I can deposit any material which has a lower melting point significantly lower melting point compare to the source material. There is a material of the holder right, but silicon dioxide has a extremely high melting point. In that case what can I do? I need I cannot use this technique where I am you know heating the material to its melting point because the source material will also get that the holder will also get melted right.

So, what I have to do? I have to go for another kind of deposition which is call electron beam deposition where the heating would be done through the electron beam, but this the material that we use at the bottom to hold the to hold this source material is called crucible right. In case of thermal evaporation, it is called boat.

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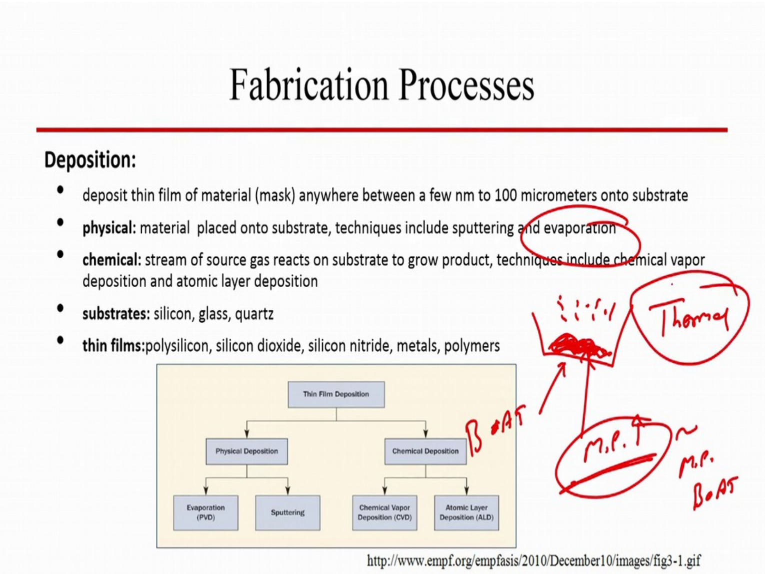

If you see this slide, this is a boat in thermal evaporation. I just give an example right; if you have a material on the boat if you heat this boat such that it reaches the melting point of this material melting point of this material and high, then what will happen? This material will get melted and then it will start evaporating and depositing on the substrate, is not it?

Now, the question is if the material that is loaded into the boat has an extremely high melting point or is melting point is equivalent to the melting point of the boat; boat is a holder this is a boat ok, then what will happen? I cannot use thermal evaporation; I cannot use thermal evaporation. So, instead of that I can use an electron beam operation and as I just told you that in electron beam operation, the source material is loaded in a crucible. This crucible is made up of carbide or quartz or a very high melting point material.

In this crucible, I will load the material that I want to deposit. And then electron beam electron beam will be incident on this particular material and the material starts evaporating. The cooling is done with the help of helium on the backside help of helium on the backside.

And then substrate will be coated with this particular metal the advantage here is that the using electron beam we do not required to actually worry about thermal evaporation because we are not melting entire thing, only a part of it and because of the electron beam intensity this only the part of that material will get melted. And you have a cooling way from the back side which is your helium so, that the crucible is not destroyed alright.

So, we will discuss this about e beam evaporating in detail and just helping out to understand that. In case of thin film deposition, there are various techniques to deposit this thin film right and depending on what kind of film, you want to deposit silicon dioxide silicon nitride metal or polymer or polysilicon. You have to change that particular technique; when I should use sputtering, when I should use evaporation, when I should use CVD right, when I should ALD. So, this concepts we will be looking at.

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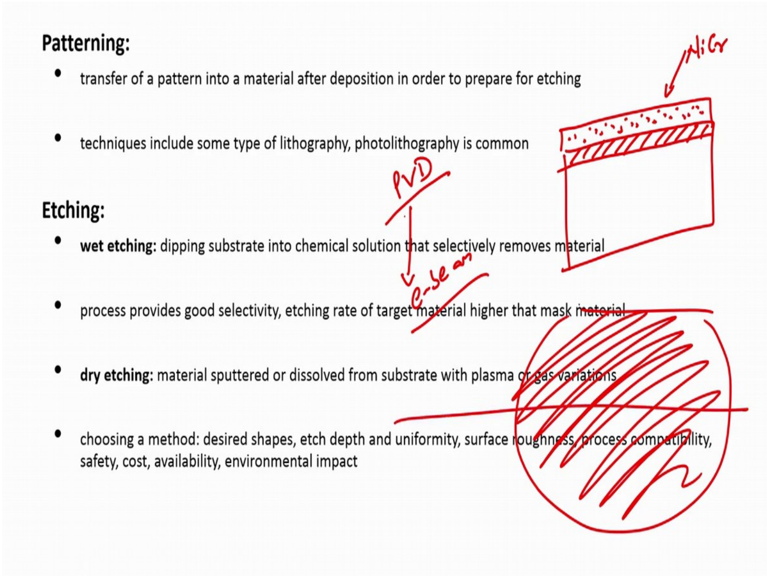

Now, very important point that we need to understand is the patterning. Patterning is what? So, you remember right that we took an example of oxidized silicon vapor on which we have deposited nichrome right. This nichrome, we are depositing using a PVD technique. PVD is Physical Vapor Deposition and in PVD, we are using electron beam evaporation to deposit this particular material which is our nichrome alright. These all cross section if I draw it, it is like silicon vapor coated with oxide or which there is nichrome alright; if I have a cross section of this it will look like this.

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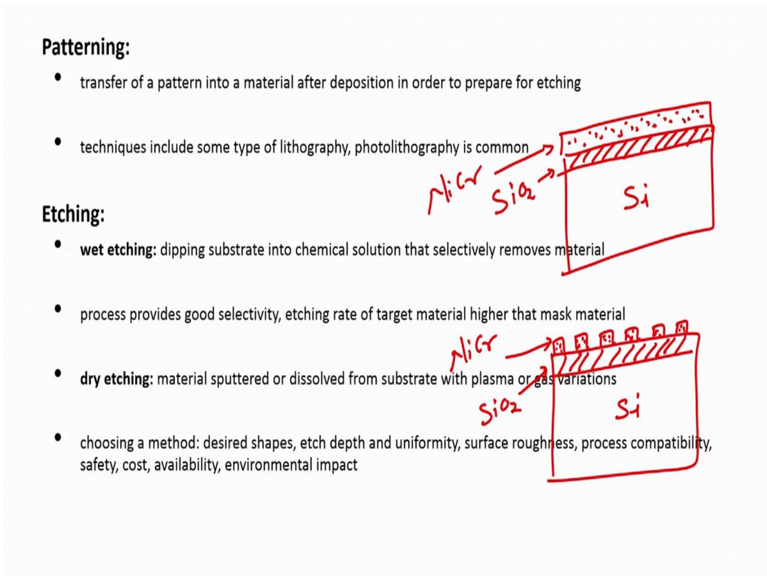

So, once you deposit this the nichrome on the oxidized silicon vapor, then what is the next step? What is the next step? You have to pattern this nichrome such that I will have a heater right; I have to pattern the nichrome such that I can fabricate a micro heater. So, how to pattern this pattern this material? So, now, you have a nichrome micro heater and you have silicon dioxide and further you have silicone correct. If I draw the front view or top view top view, will look like this where I will have this material pattern in this form patterning a cross section of this entire vapor, then I will have this particular right.

So, what is a patterning? Patterning is transfer of pattern into material after deposition in order to prepare for etching transfer of pattern. So, we will see what kind of patterning techniques are there. There are several ways of patterning it, but the most commonly used is photolithography alright photolithography. So, lithography comes from a one litho and graphic which means that two curve from a single stone two curve from a single stone; lithos and graphic.

So, now we will see how the photons or the UV light. In this case UV ultraviolet light is used to pattern different materials on to the substrate right.

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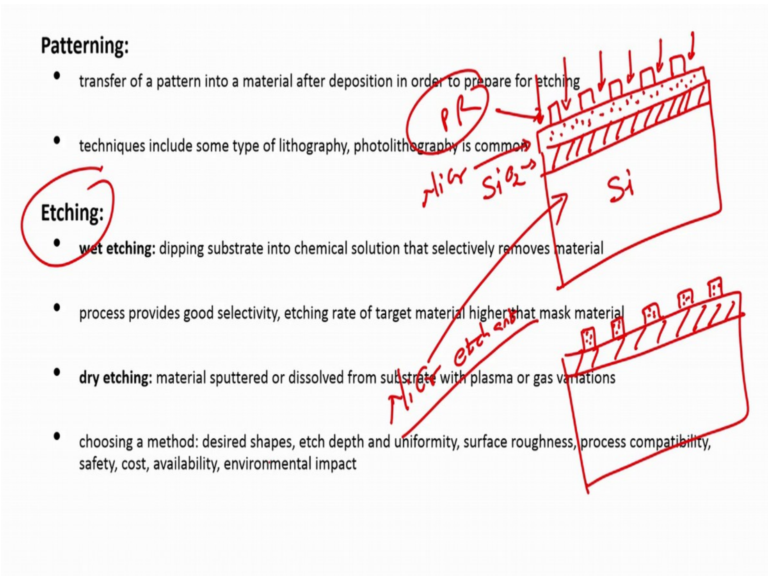

Now let us see another term called etching. So, what is etching? So, you see when I have a material right; when I have a material silicon dioxide I have silicon, then I have my nichrome right.

Now, I need to protect my nichrome in certain area and remaining that I will want to etch it, why? So, that finally, what I will have sorry this protection we can use it photo resist; photo resist. So, finally, what I want is the nichrome present only in this area, the other area it should be removed that removal is called etching ok. So, how can I protect this nichrome? By using my photo resistor. How can I pattern my photo resist in this fashion? Using photolithography alright.

So, photolithography using photolithography, we can pattern the photo resist and this photo resist will it is a mask against the chemical that is used to etch the metal below it or a material below it. In this case, it is a nichrome right. So, wherever the photo resist was there, you can see that nichrome is still present is not it? Now what is the next step? Next step is that if I did this vapor; if I did this vapor in nichrome etchant nichrome etchant, what will happen? The nichrome where it is not protected by the photo resist will get etch; in nichrome which is not protected by photo resist will get etch right.

So, if I use a nichrome etchant which is a chemical, then that is called wet etching right because you are dipping the vapor in a chemical. Chemical is a solution that is used to etch the nichrome and equal the wet etching. So, wet etching is where we dip the substrate into chemical solution that selectively removes the material what about selectively removes the material. That means, that it will not affect photo resist and it will only etch the nichrome right.

Now, process provides good selectivity etching rate of target material higher than the mask material. What does that mean? That you if you use silicon dioxide is a masking layer that will protect the nichrome below it right, then this photo resist should not be affected. So, the selectivity of the metal or selectivity of the chemical should be extremely high, then we should only etch the metal and it should not etch the photo resistance that is called selectivity alright. That is why provides good selectivity etching rate of target material higher than the mask material right.

Next one instead of wieght etching. If I use gases to etch the material, then it is called dry etching because there is no wet component in world. So, dry etching is where you material sputtered or dissolve from substrate with plasma or gas variations. If I use two different gases such that will affect the metal and the metal will get etch is called dry etching right.

So, its very easy. Now for choosing a method desired shapes; if we see the slide, you can see that there is a desired shape, etch dept, uniformity, surface roughness, process compatibility, safety, cost availability and environmental impact. When you choose the method you should take care of all these parameters. If you go one by one is what is the desired shape right?

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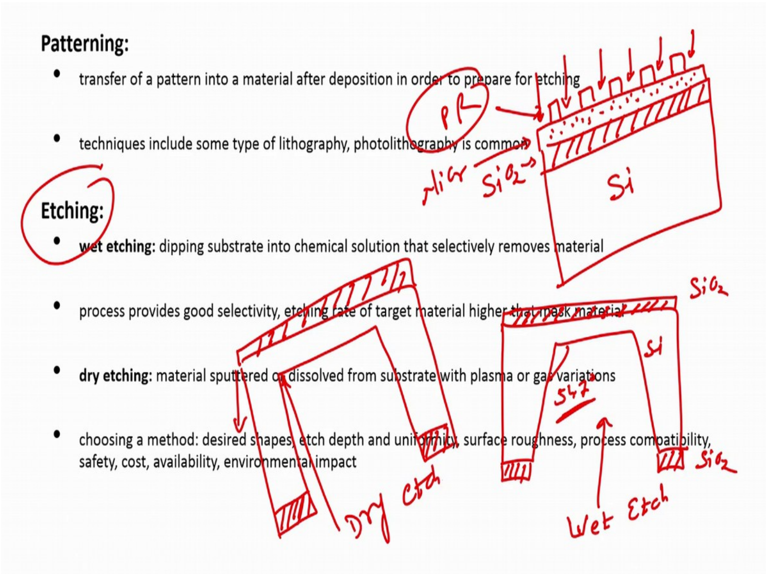

Because if I etch silicon vapor; if I etch silicon vapor from backside, I will have a 54.7 degree angle. If I etch silicon dioxide right from the backside to create this diaphragm and this is my silicon dioxide, this is silicon vapor silicon dioxide. If I etch it, then what I am getting? A angle of 54.7 degree this is using wet etching wet etching right.

But if I use dry etching; if I use dry etching, then I will have this pattern. So, what is application? Are you with this 54.7 angle or you want it to be edge in this particular shape desired shape? If I want this shape, I will go for dry etch right. This is what we call about desired shapes. Then second is etch depth right; if I want to etch for let say out of 500 micron silicon vapor. If I want to etch 400 microns vapors right and with uniformity, what kind of process I should select wet etching or dry etching?

Next is the surface roughness the roughness of this material; this wall is very important in our one of applications. So, what is surface roughness of this wall? If I use wet etching is it faster than dry etching, it is less costlier than dry etching right. So, but what about surface roughness? Surface roughness will be better in dry or in wet. So, all this parameter we have to understand process compatibility right; whether the wet etching the chemical will affect the photo resist or a massing layer or dry etching will affect right ah. When you could talk about wet etching again in wet etching there are several processes that are used for etching silicone.

For example, if you take about talk about silicon then there is a KOH with this potassium hydroxide and there is a tetramethylammonium hydroxide TMAH which are used to etch the silicon vapor or silicon material. Now, if I use KOH and if I use TMAH which one is advantageous, again I need to see the first is you have to select dry etching or wet etching, then within wet etching what kind of process within dry etching what kind of process right. So, next is safety which one is safer. I have potassium hydroxide if I have TMAH both are wet etchants which were I will use right.

So, I know that potassium hydroxide is faster, but TMAH is slower, but it will give me smoother edge edges; however, TMAH is a neurotoxic where KOH is not right. So, if I have a proper fume hood a good environment everything is perfect, I am working in an a class 1000 10000 environment with the proper fume hood and proper wet benches right; acid bench, solvent bench everything and then I am using a process.

Even the material is neurotoxic it does not matter because I am not putting my head. I have seen lot of people putting their head within the fume wood, it is not allowed fume hood is meant only to put your hands not your head. Otherwise why you require wood, is not it? You just you have to put your hand and you want to work in their fume hood or in the wet bench.

Any chemical process please do not smell it; please do not put your head inside this particular equipment wet bench alright. So, then next is a cost; if I use dry etching and if I use wet etching, which is more costly right? For most of the time wet etching is cheaper compared to dry etching; dry etching is costlier; however, dry etching has its own advantages. Finally, environmental impact the residue gases residual gases from the dry etching right will it affect environment more or the residue gases with or the waste chemical after the wet etching that will affect the environment more.

So, there is another thing that we need to understand alright. So, these are the things that you know understand when you are patterning and etching.

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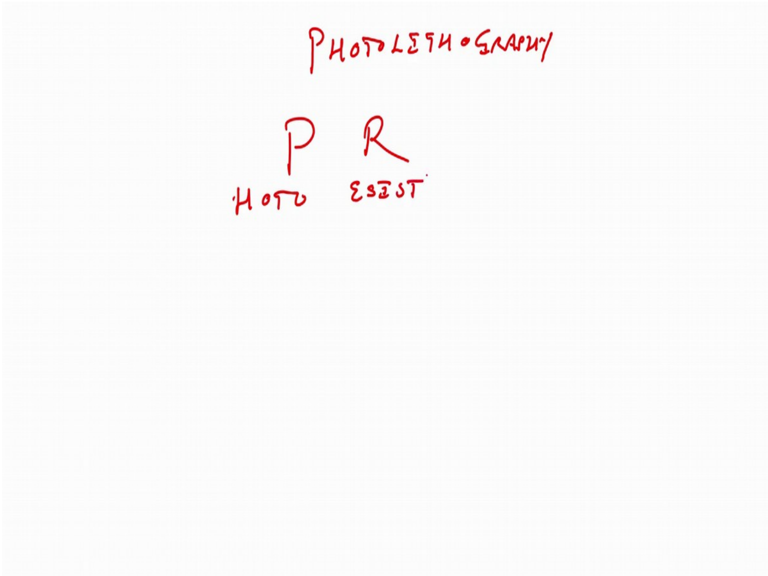

Now, let us see photolithography; very very important topic. If you see the slide photo litho this is l i t h o litho graphy alright photolithography. We need to understand that what techniques we have to use for fabricating or for patterning the material alright. So, for that what we will do; what we will do? We have to use a polymer called photo resist; photo resist right photo resist alright. Now photo resist is in short it is called P R ok.

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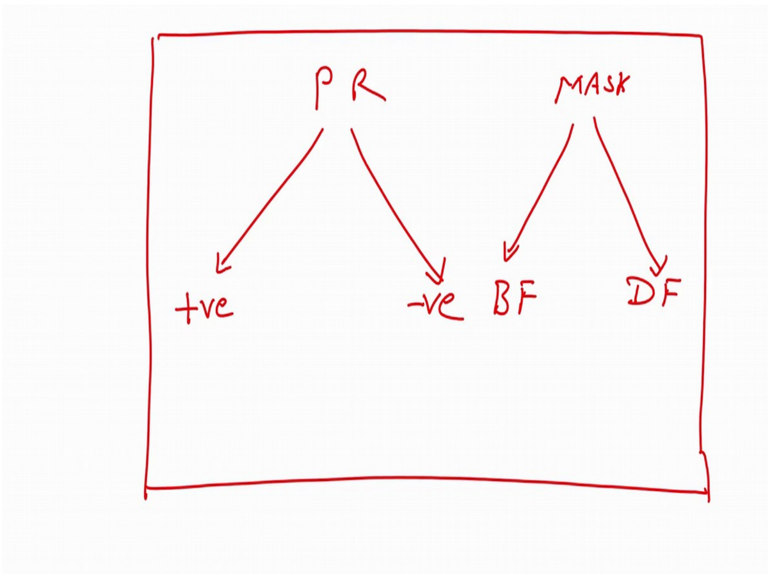

So, photo resist are of two kinds or two types; positive photo resist and negative photo resist two types positive photo resist and negative photo resist. Then next step you need to understand is called mask. Masks two types; bright field mask and dark field mask; bright field mask and dark field mask. If I have this is a mask, this is this rectangle is my mask boundary alright and only this letters that I have written here right or this symbols that I am using positive negative bright field dark field mask P R. This arrow these are only dark, otherwise my entire field this one this is everywhere is bright is transparent. This is my bright field mask, this is my bright field mask right.

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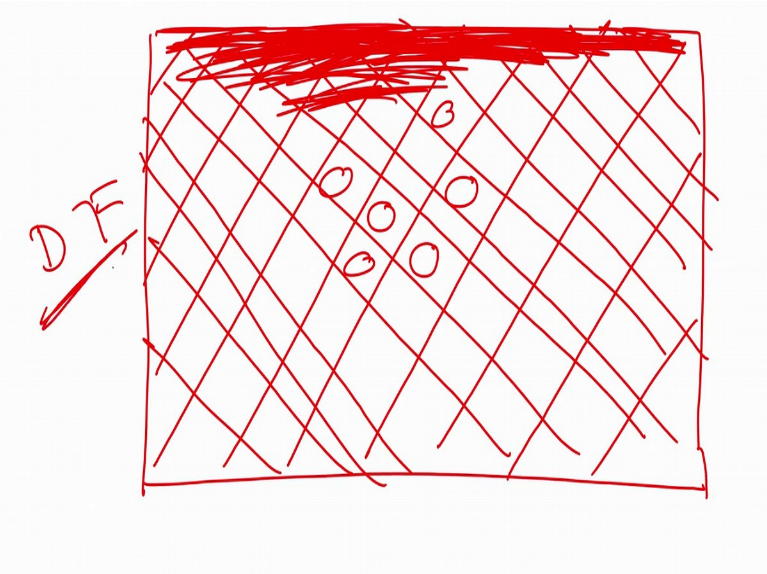

Instead of that if I want to if I have this entire box alright you assume I am just drawing lines, but you assume that everything is dark; everything is dark alright everything here is dark. And only the pattern that I am drawing here; let say this circle; this circle bright these are bright. Everything is dark these all the check is this is like dark completely dark like this ok. I am just I do not want to waste time in drawing the entire mask darker like this right.

So, assume that everything is dark like this and in that only the circle that I have drawn only the circle that I have drawn is bright is transparent. This is your dark field mask dark field mask. I will show it to you once again the dark field mask so, that you understand that how it looks like. Now what is point of discussing about dark field or bright field right? So, what is a point you see in bright field mask, you will have the same pattern; you can replicate the same pattern which was there in the mask what does that mean.

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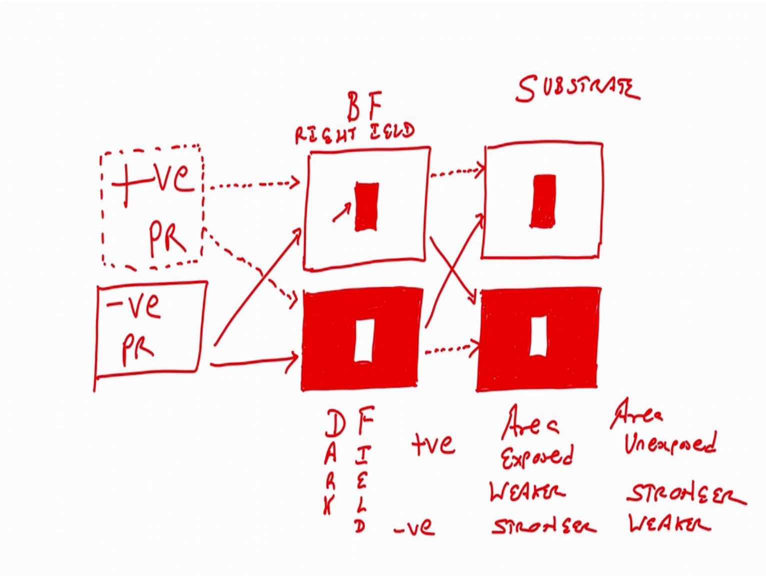

So, if you see the slide; if I use a positive photo resist positive photo resist alright and I use a bright field mask. Let say we have this is my bright field mask and then another one, this is my dark field mask. I quickly draw it. So, you understand the role of the positive photo resist and negative photo resist in lithography. So, very very important to understand this photolithography because it is considered as a heart of any microsensors or micro fabrication technique; photolithography is considered as a heart of micro fabrication microsensors fabrication technique alright.

So, dark mask looks like everywhere it is dark except the pattern like this. So, now, what I want to show it to you is that if I use a positive photo resist with my dark field mask and with my bright field mask, what will happen and if I use negative photo resist with my bright field mask and dark field mask then, what will happen? This is what it is a dark field mask right. Now you say it is a dark field mask; this is a bright field mask.

So, bright field dark field f i e l d; f i e l d dark d a r k right like that bright; you know bright b r i g h t b r i g h t bright field f i e l d bright field dark field. Now if I use positive resist and if I use bright field mask and dark field mask like this, then what kind of pattern I will have on silicon vapor? So, this is a silicone vapor alright, then here sorry I let me just draw rectangle substrate it becomes easier for you to understand; rectangle substrate like this alright. Then when I use bright field mask and positive photo resist, then I will have this pattern. When I have positive photo resist and dark field mask, then I will have this pattern; the one I am drawing

So, what you see is that whatever pattern was there on the mask whatever pattern was there on the mask is same the same pattern is transferred onto the substrate right. You see the dark field mask how it was looking you are looking same like what I am drawing here. The same pattern is transferred or is retained onto the substrate onto the substrate that is the; that is the advantage of using positive photo resist or that is the role of positive photo resist or you can say characteristics of positive photo resist that it will retain the same pattern as on the substrate right say. This is what I will have if I use my positive photo resist; this is my substrate.

So, if I use my bright field mask, I will have the same pattern if I use dark field mask I will have my same pattern, but this is for positive photo resist; this is for positive photo resist right. Instead of that if I use negative photo resist negative photo resist; so, if I use negative photo resist with bright field mask right what I will have is this kind of pattern. And if I use negative photo resist with dark field mask, I will have this pattern; you see opposite. If I use positive photo resist so, let me just draw positive photo resist with this kind of arrow or dotted arrow. If I use positive photo resist, I will have this pattern and with this mask, I will have this pattern.

But in case of negative photo resist if I use bright field mask, I will end up with this; if I use a dark field mask, I will end up with this pattern. So, what we understand? We understand that you I told you right there is a UV light that we are using it in photolithography. So, here what you understand is that when I use positive photo resist when I use positive photo resist, then the area which is not exposed; you see I let me just remove this arrow for the negative.

So, it is not confusing for you are you see here only for positive photo resist ok. We are talking only for positive photo resist in case of positive photo resist the area which is not exposed by UV light the area which is not exposed by UV light will be stronger. You can see here this area is not exposed. So, it become stronger this area is not exposed, it became stronger correct.

Now, in case of negative photo resist if I talk about negative photo resist, then the area which is not exposed the area which is not exposed becomes weaker right and area which is exposed right will become stronger, you see. This area is exposed, this transparent thing is exposed. So, we have here this pattern in this case negative photo resist, I am talking about negative photo resist. In this case bright field mask, the area that is exposed and the area this is not exposed will be weaker you can see here right. That means, that if I am using positive photo resist then the area which is exposed and the area which is unexposed a expose and unexpose is with respect to UV light right.

So, in case of positive photo resist the area which is unexposed gets stronger, the area which is exposed becomes weaker. In case of negative photo resist the area which is not exposed becomes weaker, the area which is exposed becomes stronger right easy. This is very important to understand ok; that is why we are talking about this extremely important understand, how you are using or when you will have to use a bright field mask dark field mask, how the area which is exposed what kind of pattern you will get the area is not expose with UV light what kind of pattern, you will get.

So, extremely important to understand bright field mask and positive photo resist, dark field mask and positive photo resist, bright field mask and negative photo resist, bright field mask, dark field mask and negative photo resist. Now very simple concept is whatever the pattern on the mask is there same patter, we can transfer on the vapor or substrate when you are using positive photo resist, but when you are using a negative photo resist then whatever the pattern is that the opposite pattern will come on the substrate alright.

So, another way positive photo resist area which is not exposed becomes stronger, negative photo resist area which is not exposed becomes weaker. Positive photo resist area which is exposed becomes weaker, negative photo resist it area which is exposed become stronger right very easy; extremely easy to remember alright.

So, what I feel is now let us end this particular module here and we will continue in the next module where I will talk about the process that we use to pattern the vapor. What are the process right? We will take one example and so, that you understand; we will take very simple example of a heater right. So, that you get the point that what kind of technique or what are the processes involved, what are the steps involved in photolithography right.

Till then you look at this module. If you have any questions ask us through the NPTEL forum and we will be able to answer your queries right. Till then you take care, I will see you in the next module, bye.