Fabrication Techniques for Mems-based Sensors: Clinical Perspective
Prof. Hardik J Pandya
Department of Electronic Systems Engineering
Indian Institute of Science, Bangalore

Lecture – 04
Silicon, silicon di-oxide and photolithography

Hi, welcome to this class. This class is divided into 2 or 3 modules we will see and we are focusing on Silicon, silicon di-oxide and photolithography. Now, if you understand photolithography, photolithography is the heart of any micro fabrication or micro engineering process. So, it is very important to learn and understand how we can perform photolithography. But before we understand photolithography most of the substrates, most of the devices in semiconductor area or arena is made about made out of semiconductor right and that semiconductor is nothing, but silicon.

So, we should first understand how we can get a silicon wafer right, because that is the substrate that we will be using. Now, when we talk about substrate what exactly a substrate means, substrate means any material on which you are going to fabricate a device. Now, whether it can be whether it is a metal or a semiconductor or insulated does not matter. The base that we are using to construct the device the base is called a substrate.

Now, if you have seen generally a MOSFET's or transistors right a MOSFET is also a transistor BJT's or even some accelerometers some sensors, pressure sensors right; they are all fabricated on what on silicon. So, when we talk about silicon how silicon wafer looks like right. So, I have a silicon wafer in my hand.

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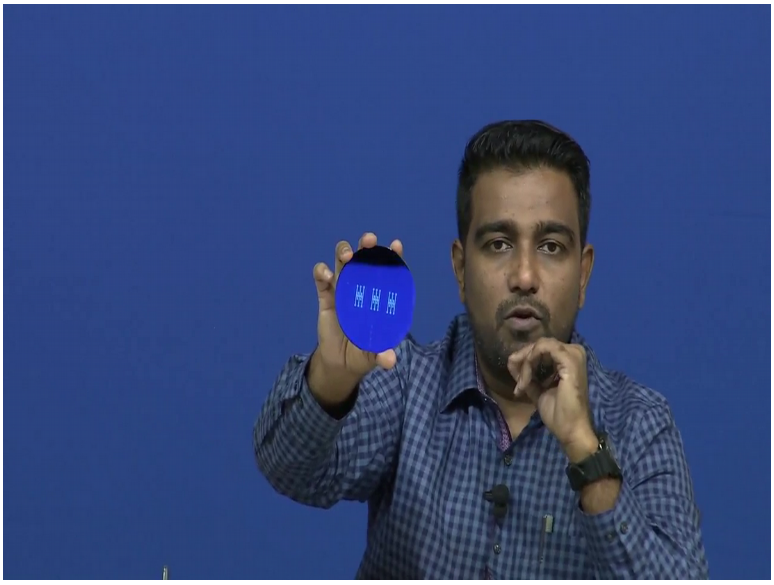

You can see here this is a silicon wafer now you see here right this is a rough surface. How you can see it is a rough surface because, on another side you can see is a polished surface right, you can see very clearly a polished material. There is some pattern on silicon wafer that is you do not have to worry about it right now, but the point is you can see a silicon wafer right in my hand right. Now, this silicon wafer it is a 4 inch silicon wafer. So, let me hold it in a way it should be hold it; first of all you should not hold it with bare hands you have to wear glows, but this is just for demonstration that is what I am holding with bare hand.

As you can see the there is a flat surface here you can see a flat there is a one flat, there is a second flat; this flats are meant to understand whether it is P type or N type or it is 1 0 0 or 1 1 1. We need to understand what kind of wafer it is and what is a orientation of the wafer, to understand this orientation and the wafer type we are using the flats right. So, flat can be at 90 degree as shown in this wafer, it can be at 180 degree, it can be at 45 degree or it they can be only one single flat.

Now, the big flat that you can see here where my thumb is you can see here right. This is a big flat while, there is a small flat right over here this is a small flat, this is a big. So, primary flat and secondary flat we say like this primary flat and secondary flat, primary flat is bigger secondary flat is smaller.

Now, in some way for you will only find primary flat, again like I said to distinguish the type of wafer and it is orientation we have the flats placed into the wafer. Now, but the question is how can you fabricate this wafer, why it is called wafer you can see is thin in size right is extremely thin. Now, it can be 100 microns, it can be 200 microns, 300 microns in thickness, this is a 4 inch wafer. The one that I am holding right now is a 4 inch wafer, 4 inch wafer with a thickness about 400 to 500 microns alright.

So, this is the wafer, so now you can see here there is a rough surface and there is a polished surface. So, again when you talk about wafers they are polished wafer or unpolished wafer. Now, if it is one side polished is one side polish is called single side polished wafer. If the polishing is done on both side, it is called double side polished wafer. Now, depending on the diameter of the wafer, diameter of the wafer this is a 4 inch wafer like I said earlier and the diameter of the wafer the thickness varies. So, for this wafer that I am holding the thickness is about 500 microns 500 plus minus 50 that is what it is written in the specification 500 plus minus 50 microns in thickness, so this is the 4 inch wafer.

Now, substrate when you talk about substrate; substrate can be a glass also. So, this is a glass substrate you can see here again I am holding in my hand right a glass substrate, a glass substrate right. So, you can you can clearly see it is a glass right on which again there is a pattern some pattern is there on the glass. This is again a wafer and it is a 4 inch wafer, 4 inch wafer about 100 microns thick 100 microns thick right. So, this glass can also be used to fabricate device, you can see some pattern on this glass this is nothing, but a heater.

Heater we have pattern on this glass and we will discuss about these things how we can pattern different materials or different components or different devices on different substrates in a later section of the, this particular course. The idea right now is to understand: what are the kind of substrate in particular silicon. So, this is another type of substrate, now let me show you one more type of substrate and this substrate is using a plastic a plastic. So, I am holding another substrate in my hand this is using plastic the best bare plastic. So, you can fabricate a subs you can fabricate a device on something which is similar to a plastic right.

So, plastic can be a substrate again there is some pattern on this plastic right. So, plastic can be a substrate, a silicon can be a substrate, a glass can be a substrate right. Now, the question here that we need to understand or the point here that we need to understand is. How we can get this silicon wafer, because silicon 70 percent or more than 70 percent of the devices today available around us the base is silicon. So, when we talk about silicon how we can get the silicon of from the raw material alright that is the idea to understand in today's module. So, when we talk about silicon let us see on the screen right let us see on the screen silicon.

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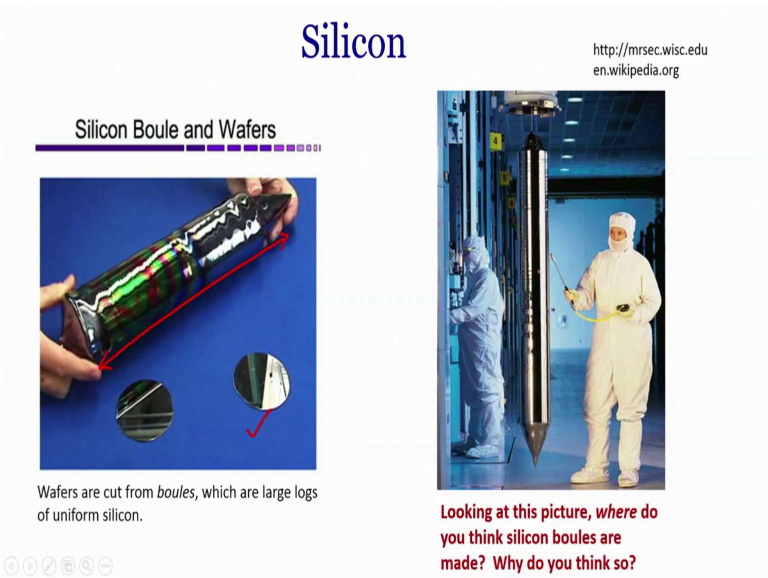

So, silicon boules and wafers right we have seen just a wafer right now right 4 inch wafer. And this wafer are cut from the boules which are large logs of uniform silicon right like this. Now looking at this picture where do you think silicon boules are made and why do you think. So, that is a question so of course, we can see that it is made the silicon boules are made in clean room clean room. So, when we talk about clean room clean rooms are classified into several class.

And we to in the, this particular course we will see class 10000 10000 clean room facility. I will actually show you how the class 10000 clean room facility looks like right. I will take you to my lab of course, through videos and you happen to be in IISC in one fine day and you want to visit my laboratory you are welcome to do. So, class 10000 clean room facility, so how it will look like. Now, this is what we will be looking at, but when we look at the silicon this is even at a lower class that is a better environment it can be at class 10 it can be at class 100 and it can be a class 1000 So, we will see what are the class and what are the clean room classes how clean room is a classified.

Now, why we think that this is a clean room right; First I think we answered where do you think silicon boules are made, we think that they are made in a foundry under clean room which has a which has a clean room facility right. So, first we have answered why do you think so why we require clean room what is the answer. The answer is to avoid contamination right, we need a silicon which is 99.123456789 and 9 9 times 9 pure.

So, to obtain this we require a clean room facility and this clean room facility is a place to avoid any contamination. So, now we know that if a boule is there if you if you have a boule then we can slice the boule and we can get the silicon wafer of course, there is a process we will see the process also.

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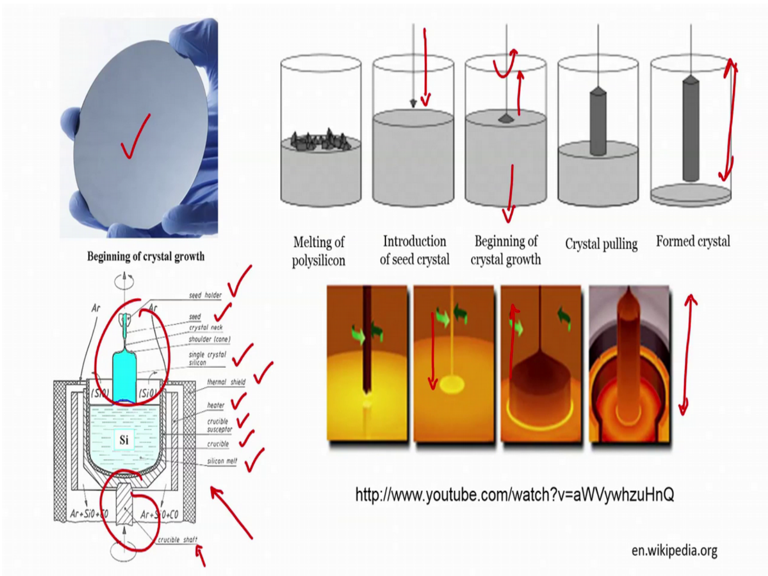

So, this is what we want right this is what we want and how it is made. So, the initially melting of poly silicon the poly silicon is melted right. At very high temperature and you can see in this particular figure that there is a crucible right there is a crucible, there is a crucible shaft.

Which helps the crucible to rotate then we add the silicon poly silicon crystals. So, there is a silicon melt here there is a crucible here the crucible susceptor is there is a heater surrounding the crucible and then there is a thermal chilled right. Now, we dip a seed holder seed holder with the seed cryst like this, a seed holder with a seed crystal inside this hot molten poly silicon. Now, when it is dipped right and when it is pulled back pulled back with rotation with a rotation. Then it starts forming a single crystal right seed crystal is a single crystal.

Where you dip the seed crystal into the molten poly silicon and you start pulling off we with the rotation and the crystal starts growing. So, this is a beginning stage of the crystal, now when you start pulling the crystal it is starts forming the forming the single single crystal silicon. And at the end you will be able to see the boule that we will be we were looking at in the last slide. So, this is how the boule is made.

You can see from here a melton silicon the seed crystal is inserted you can see here it is inserted. And now it is pulled back it is pulled back right. And once it is pulled back you can form a single crystal silicon rod or a boule. Now, one thing that you need to understand is that both the shaft and the seed crystal hold seed crystal both moves in a opposite direction, both moves in a opposite or anti-clockwise one is clockwise second one is anti-clockwise direction.

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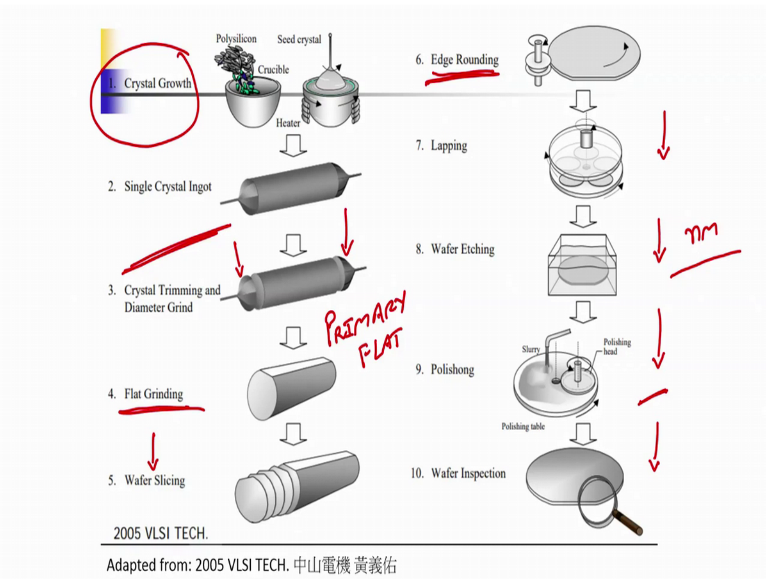

So, once you have the single crystal ingot it is also called ingot or boule. Then what you will do first is you have to grind and trim the crystal you have to remove the edges right. So, this you see here we have trimmed the edges. Next what is the process next process is you have to flat perform a flat grinding why you want to perform flat grinding. So, that we can get the primary flat, we are just seen right how primary flat looks like. So, to get primary flat we have to do a flat grinding.

After flat grinding we have to perform wafer slicing right wafer slicing wafer slicing is done using a diamond thread. Now, after wafer slide you have to perform edge rounding right you have to round the edge then there is a process called lapping followed by chemical etching followed by polishing right. Lapping wafer etching followed by polishing wafer etching is to get smooth wafer smooth wafer. There is a extremely smooth wafer with a nano meter finish surface finish.

Now, once you have this, once you have this what is the next step after this you have to polish it once you polish next step is to inspect the wafer right. So, starting from a crystal growth that you are loading poly silicon into the hot crucible and then there is a hot crucible poly silicon is in melted form, and then you dip the single crystal and you rotate it and you pull it off and you get single crystal ingot right.

Followed by a crystal trimming and then diameter grinding followed by a flat grinding followed by wafer slicing then edge rounding lapping etching polishing and finally, wafer inspection. This is the process that is followed to obtain finally, the wafer that we have seen at the starting of this class. These adapted from 2005 VISI tech.

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Now, this is how it will look like this is how it will look like. So, you have this boules you can see here right this boule and when you do the, etch you remove the edge by grinding you can just or trim the edge then you have this one right. And then like I said diamond coated wire is used to slice the wafers from the ingot after slicing you can use the lapping machine, you can see here a lapping machine to lap the wafer after lapping there is a chemical wedge and then polishing finally, be inspection.

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So, this is a video that you need to see. So, you understand how exactly the silicon is fabricated and just look at this video. And then we will follow the lecture after this particular video.

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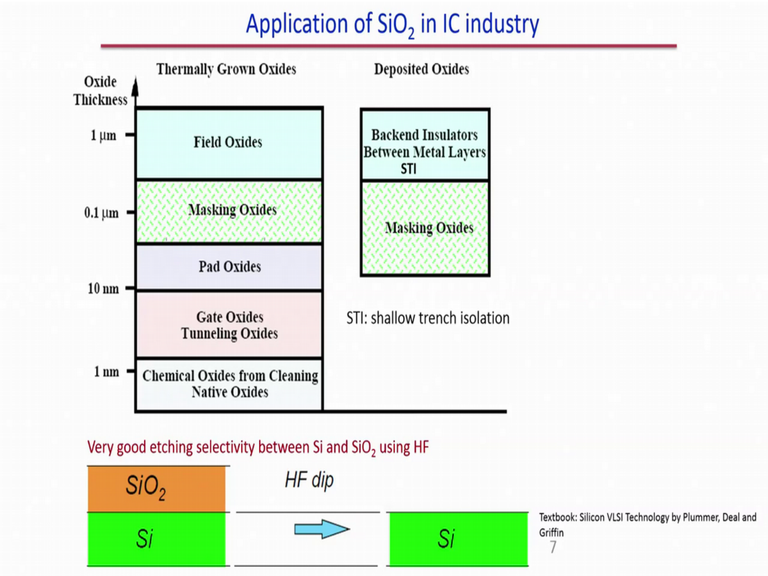

Now, once you know once you know that you had the silicon wafer right once you have the silicon let us say. What is a next step next step is you can if this is silicon and if I start depositing a material on the silicon wafer let us say if I deposit a metal, metal then what is what happens silicon is a semiconductor metal is a conductor. So, we may not be able to get what we want right, because it will be a short it will be a short between a conductor and a semiconductor.

So, how to use silicon as a substrate, so to use silicon as a substrate we have to grow a oxide layer. So, let me draw a so that we can understand. So, silicon we have to grow oxide layer onto silicon. So, that we can use silicon as a substrate this is silicon this is SiO 2 this is Si O 2. This particular wafer is called oxidized oxidized silicon wafer oxidized silicon wafer.

How you can grow this silicon dioxide, how you can grow silicon dioxide. That is what we have to understand today and the silicon dioxide is nothing, but an insulator is an insulator right. You can also grow silicon nitride, but silicon dioxide is heavily used in the IC industry. And that is why we need to see what silicon how silicon dioxide is grown and second is: what are the thicknesses of the oxide and that are used for different process. So, let us see let us see now why we have to grow silicon dioxide, because if I take the same example if I take the same example.

And if I deposit metal now right let us say metal looks like in this particular fashion this is my metal this is silicon dioxide this is silicon right. Then metal will not get shorted with silicon because of this insulating layer in between silicon and silicon oxide correct. So, I have to use oxidized silicon wafer I have to use oxidized silicon wafer. Now, let us see, so we have got different thickness of oxide we have 1 micron oxide we have 0.1 micron oxide we have 10 nano meter oxide, we have 1 nano meter oxide. So, if it is 1 micron oxide then it is used in field oxides. So, if you guys know MOSFET then you will understand a difference between gate oxide and field oxide gate oxide and field oxide.

So, 1 micron is used for field oxide 1.0 micron is used for masking oxide where masking comes into picture. So, let us see that is let me draw here if I want if I want to create a pit in silicon wafer this is silicon I want this structure. So, how can I obtain this structure see I know what are silicon etchants that can etch silicon right. This etchants are KOH potassium hydroxide TMAH tetra methyl ammonium hydroxide and.

This etchants are used for different application when I say different application, application is same which is silicon etching; but I use at different temperatures 1 KOH is generally used at 80 degree centigrade TMAH is used at 25 degree centigrade. But K when you etch silicon with KOH you get rougher surface rough boundaries. When you etch with TMAH you get smooth boundaries KOH is faster TMAH is slower right. So, these are the some differences in silicon etchant KOH versus TMAH.

So, the point is if I want to create or if I want to etch silicon in this particular fashion from a silicon from a given substrate of silicon how can I etch it. One way is you protect silicon dioxide in this you protect silicon with the help of silicon dioxide by patterning silicon dioxide in this fashion. Now, if you dip the wafer in KOH or TMAH then sorry. Then you will obtain this particular wafer how and why, because this silicon dioxide will act as a mask against silicon etchant. So, silicon etchant cannot etch silicon in this area that is what we mean by masking oxides alright, this is an example of masking oxide.

Now, same way changing the thickness of silicon changing the thickness of silicon dioxide; we can also use silicon dioxide as pad oxides; we can also use silicon dioxide for gate oxides you see gate oxide see. We all know right that when we have MOSFET we are just drawing a very simple diagram. Or let me just write down source, drain and gate right source, gate, drain this will be my oxide right. Which is extremely thin right close to 10 nano meter or even smaller even the thickness is less depending on the MOSFET fabrication and this is nothing, but my gate oxide gate oxide. So, again you can use gate oxide or tunnelling oxide depending on the thickness of silicon dioxide.

Then we can also have chemical oxide from cleaning native oxides right from clean native oxides we can have chemical oxides. Now deposited oxides can also be used on back end insulator materials between metal layers and can also be used as masking oxide right. Now, so what is what is the etchant for silicon dioxide right. We have seen etchant for silicon right how can we etch silicon, but how can we etch silicon dioxide. So, silicon dioxide etchant is hydrofluoric acid H F.

So, if you dip a wafer with silicon dioxide this is our oxidized silicon wafer right. Silicon SiO 2 SiO2 H F dip what you will get you will get silicon right. So, H F H F which is hydrofluoric acid right is the etchant for silicon dioxide. So, you have to remember whenever we use H F is for silicon dioxide. Now, in the common laboratory practice we use buffer hydrofluoric acid instead of H F we use B H F for etching silicon dioxide. So, you need to understand and remember that for etching silicon dioxide we are using buffer hydrofluoric acid in practical applications, now moving further moving further.

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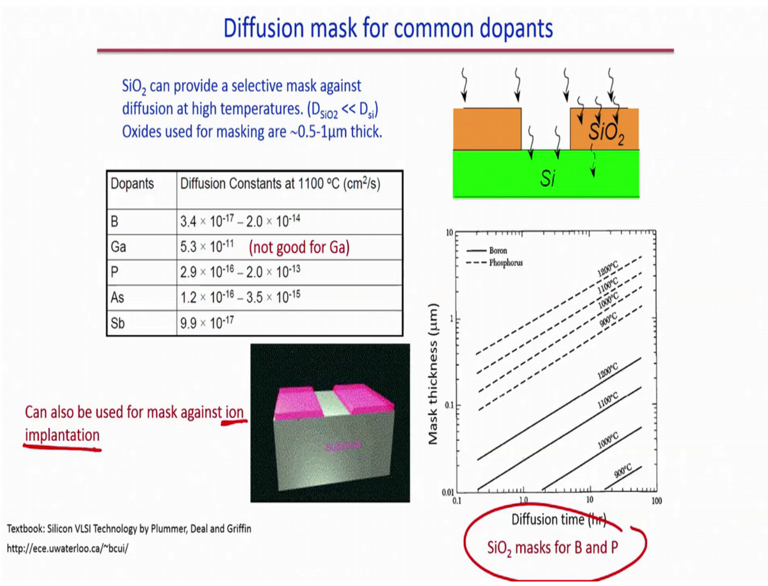

Silicon dioxide can provide a selective mask against diffusion at temperatures which are extremely high right, because D of SiO2 is extremely less than D of silicon. So, when I dope silicon right why I have to load silicon for forming source and drain right. If I want to form source and drain I have to dope it right, but if I have to dope it I have to protect the remaining area I have to protect the remaining area of silicon. So, that the doping occurs only in the required region to create my source and drain right. This doping when I perform right I am doping the entire wafer, but I am interested only in this particular area.

So, when I am doping right I can protect my area which are not required to be doped with the help of silicon dioxide. So, silicon dioxide can provide a mask against diffusion at high temperature. And what are the diffusion materials, materials that are used for diffusion boron and phosphorus boron and phosphorus depending on whether you want P type diffusion or you want N type diffusion.

Whether you want P type diffusion or you want N type diffusion whether you want N channel MOSFET or P channel MOSFET whether you want enhancement type MOSFET where you want the depletion type MOSFET right. So, this is something is very important to understand that the silicon dioxide application is not just limited for gate oxides or masking oxides or pad oxides it can also be used for as a mask against common dopants.

So, you can see here silicon dioxide mask boron and phosphorus. Now, one way of doing is of course, the diffusion technique to dope the wafer another way to dope the wafer is called ion implantation another technique for doping the wafer is ion implantation. So, silicon dioxide not only acts as a mask when we are diffusing the wafer. It acts as a mask when we are implanting the wafer both ways right, it is same thing it is just acts as a mask for against the common dopants.

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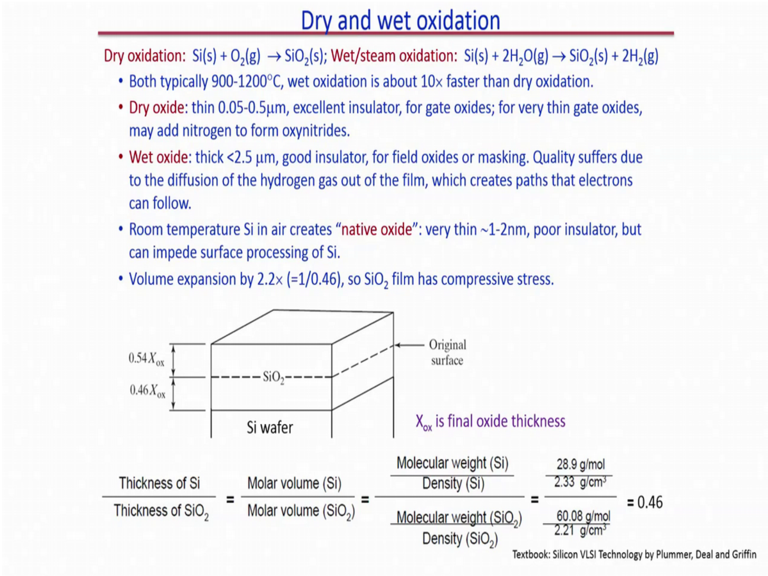

Now, we have types of oxidation one is called dry oxidation in dry oxidation we are reacting silicon with oxygen to form silicon dioxide. While in wet oxidation we are allowing the, we are we are using the water right and reacting with silicon to form silicon dioxide plus 2 H 2 O which is your gas.

So, this is nothing, but water vapour is in gaseous format to form water vapour both typically. So, say dry oxidation as well as wet oxidation is carried out typically at 900 degree centigrade to 1200 degree centigrade. Another important point is wet oxidation is about 10 times faster then dry oxidation, very important to understand wet oxidation is about 10 times faster than dry oxidation.

Now, dry oxidation forms a thin film of oxide from 0.05 to 0.5 micron. And the film that is grown that is a silicon dioxide that is grown using dry oxidation is an excellent insulator for gate oxides. And for very thin gate oxides we may need nitrogen to form oxynitrides. So, whenever you want to grow silicon dioxide for gate we will be using dry oxidation. When you want to grow silicon dioxide for a masking oxide we will use wet oxidation alright. So, wet oxide if you see back on the screen wet oxide the thickness can be less than 2.5 microns. Again it is a good insulator not as good as the oxide grown using dry oxidation it is good insulator for filled oxides or masking.

The quality suffers due to the diffusion of hydrogen gas because we are reacting silicon with H2 O that is vapour. So, there is a hydrogen gas which gas out of the film creating the path that electron can follow right. So, this is the drawback of wet oxide that the quality suffers due to diffusion of the hydrogen gas out of the film and that will ultimately create a path for electrons that electrons can follow.

There is something which is always there. So, when you get a new silicon wafer and if you keep it at room temperature there will be a thin layer of oxide thin layer of oxide is a poor insulator, but can impede the silicon processing and that is why. Whenever you get a whenever the wafer is in the room temperature in the laboratory the first step that you need to do is you have to perform H F D. That will remove your native oxide and get you the silicon substrate right, this one thin layer of silicon dioxide about 1 to 2 nano meter.

So, another thing to understand about silicon dioxide tricky right tricky useful, but tricky; volume expansion right would be 2 by 2 equals to 1 by 0.46. So, SiO2 is nothing, but it performs a it has a compressive stress. Now, this kind of thing we need to understand when we fabricate a micro cantilever right because we have to compensate the stress created by silicon dioxide by using another film which can be silicon nitride. So, you can see here very clearly silicon wafer right and how the final thickness we can obtain from silicon dioxide right. Depending on the molar volume of the silicon depending on the molar volume of silicon dioxide molar volume is nothing molecular weight by density.

Same thing the molecular weight of silicon is 28.9 grams per mole density is about 2.33 grams per centimetre cube while we talk about silicon dioxide it will be 60.08 grams per mole by 2.21 grams per centimetre cube. That is why we get this 0.46 factor and we can use this 0.46 factor to understand what is a compressive stress created by the silicon dioxide film that we are growing using either dry oxidation or we are using are using the wet oxidation technique right. So, in the next module we will be learning the techniques to grow silicon dioxide what we are learn on little now. We are learn on until now is how to how to get a silicon wafer from the mould from the boule and also from the ignot or ingot from the ingot. And how to create the silicon wafer from poly silicon to silicon that is what one thing we understood.

Second thing we understood is that substrate can be of different type can be silicon glass or plastic third thing we understood is how can we grow silicon dioxide on silicon wafer. So, the growing techniques we will understand, but what are the use of silicon dioxide, if we grow on silicon wafer right. So, in the next module let us see: what are the techniques to grow silicon dioxide we have seen dry oxidation and wet oxidation, but how the equipment will look like alright. That we will see in the next module followed by what are the characterization technique how you know what is a thickness of the silicon dioxide alright.

So, till then you learn this class and learn this lecture and I will see you in the next module bye.