Introductory Neuroscience and Neuro-Instrumentation
Indian Institute of Science, Bangalore
Lecture 26
Basics of Silicon Dioxide: Oxidation, Characterization and Applications

Hi, welcome to this particular module. In this module, we will look at silicon dioxide. In the last module if you recall, we have seen the silicon process to develop or fabricate a silicon wafer. Then we have seen what is the importance of silicon in IC industry and we also saw Miller indices that will help to understand the orientation of the silicon wafer. Now, let us understand what is silicon dioxide, and the importance of silicon dioxide not only in sensor fabrication, but also in the electronic industry is vast, and it is very very important.

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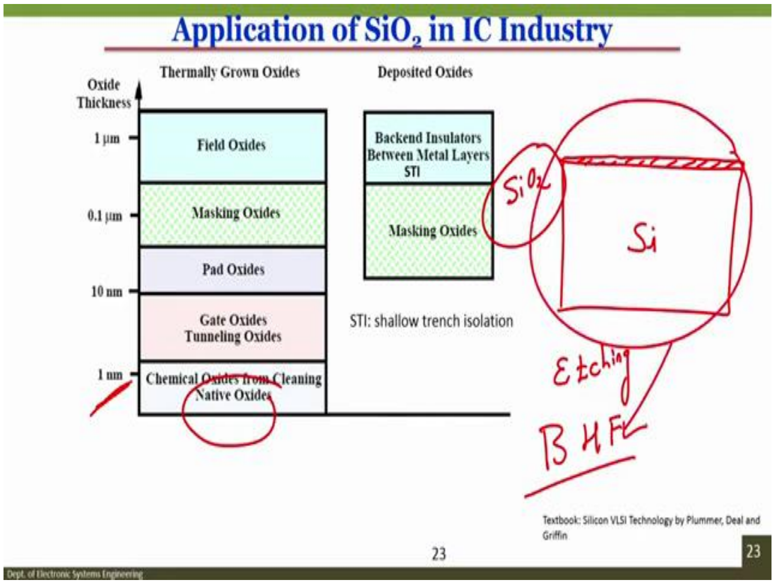

So, if I show you the screen, what you can see is, that depending on the thickness of oxide, the application becomes different. So let us start with the minimum, which is 1 nanometer. So whenever you take a silicon wafer and the silicon wafer is in contact with the environment, then it will develop a thin layer of silicon dioxide, when it is in contact with the environment, it develops a thin layer of silicon dioxide.

So this silicon dioxide is not useful, we do not require it. And to remove this silicon dioxide, we say instead of removing, the technical term is etching. To etch silicon dioxide from the silicon which is your native oxide, this is called native oxide because we have not done any particular process to form this silicon dioxide, it is formed on silicon because silicon wafer is in contact with the environment.

And since our environment consists of several oxygen, it will react with silicon to form silicon dioxide and this silicon dioxide is not useful, so we have to etch silicon dioxide. For etching silicon dioxide, we will use the chemical called buffer hydrofluoric acid, BHF. So if you dip the silicon wafer, this wafer if you dip in BHF, then what will happen?

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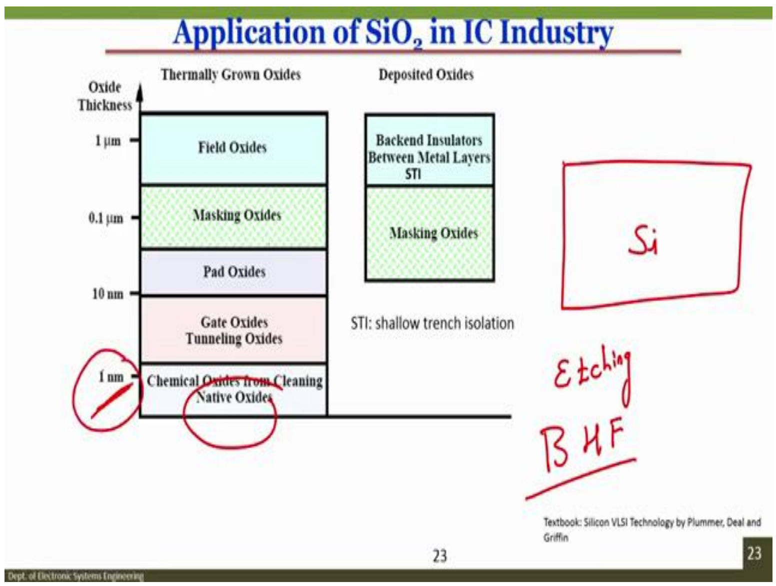

You will see that the native silicon, the native oxide that was grown on the silicon wafer will get etched. So, this is the native oxide is close to 1 nanometer. Now that is about the native oxide. Now let us understand the gate oxide.

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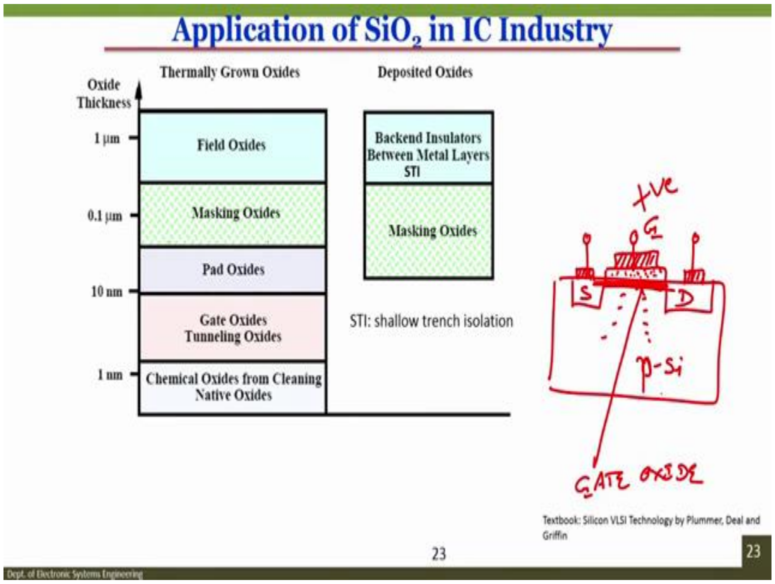

So those who are from an electronics background, you will know a little bit about MOSFET. And if you know about MOSFET there is a source, drain and gate, source, drain and gate. You get this can be metal again. This is contact for source, contact for drain. And this oxide is your think layer of SiO2 which is also called gate oxide, which is called gate oxide. What is the use of this oxide?

You see, if you have a N-channel silicon wafer and you want to, let us say P-type silicon wafer, and you want to have the channel form between source and drain then what you will do, you will make gate a negative, will make gate negative with respect to the source and drain. So what will happen, if negative is there then holes will be attracted. Is that what you want? You want holes to be attracted? No. So you have to make gate positive with respect to source.

Now, if you make positive, then what happens, the minority carriers in the P-type silicon wafer will be attracted towards gate and form this particular channel between source and drain. So when you make gate positive with respect to source and drain, the minority carriers in the silicon wafer which is p type silicon wafer, which are electrons will be attracted towards gate and forms a channel. So what happens if there is a formation of the channel?

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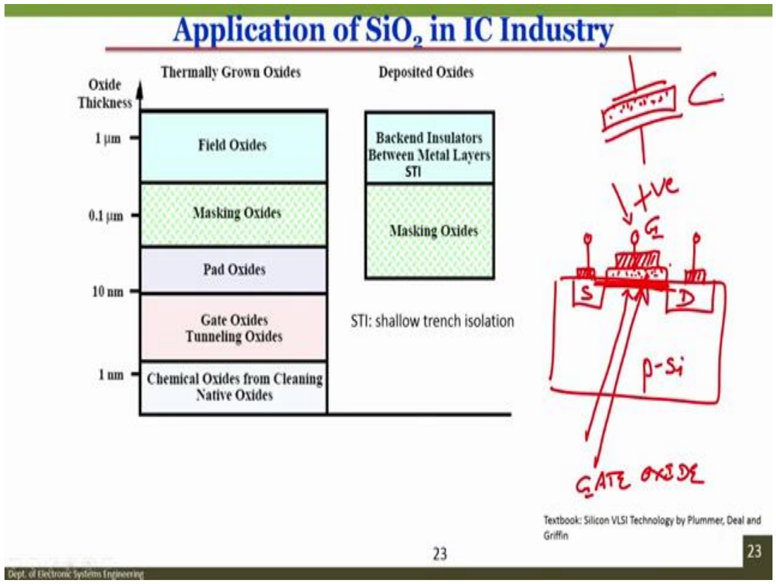

You can see that this channel is conductive. This gate is also conductive and in between, there is silicon dioxide which is this one, which is an insulating material. That means, you have two conducting plates separated by an insulating material and that becomes your capacitor. So anyway, that is details about how the MOSFET will work, we are not going into that details. Right now our understanding is what is the role of this oxide?

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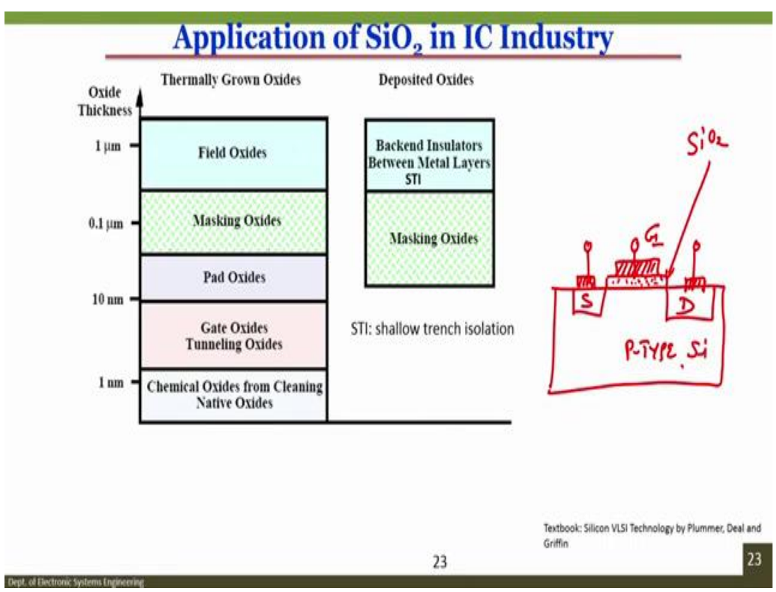

So the role of this silicon dioxide if it is between 1 and 10 nanometer you can use as a gate oxide, which is this one. Now, let us see masking oxide. What is masking oxide?

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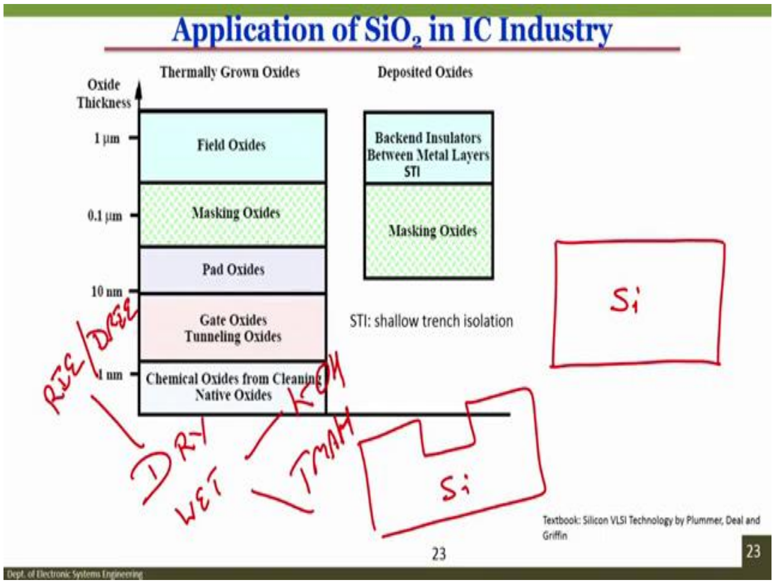

So let us take an example of masking oxide. I have a silicon wafer, silicon wafer. Now, what I want is, I want to create a pit in silicon wafer, like this. So, the way to etch silicon wafer is by two technique; one is called dry etching, another is called wet etching. Wet etching again two, we have potassium hydroxide and we have tetramethylammonium hydroxide.

Well dry has RIE, which is reactive ion etching. And DRIE, which is deep reactive ion etching. So, either we go for wet etching or we go for dry etching, so that we can create a pit. Now, to create this pit, if I dip this silicon wafer directly into etching, silicon etchant what will happen?

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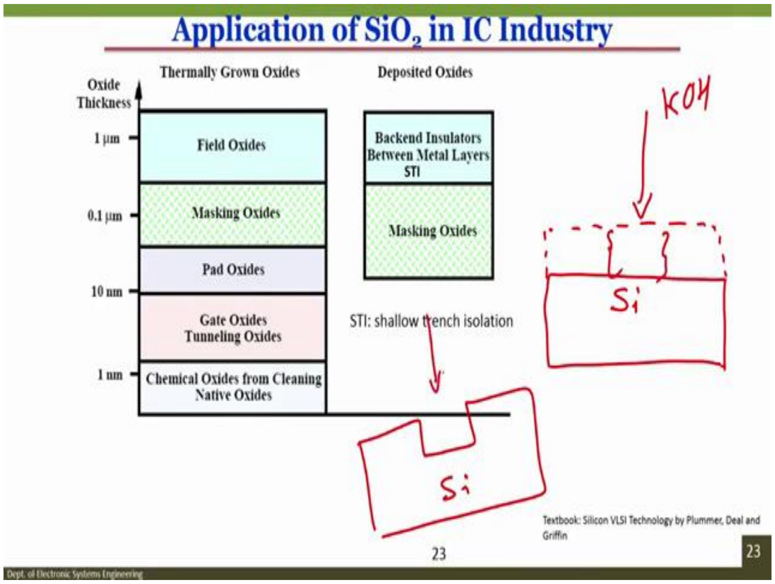

Silicon wafer will get etched, like if I dip this wafer in silicon etchant, the whole wafer will start etching. That means, it will reduce the thickness of the silicon wafer will start reducing. Initially, it was this much, after certain time, I dip this wafer, let us say in KOH, then silicon will get etched from this region, which we do not want, because we want this design.

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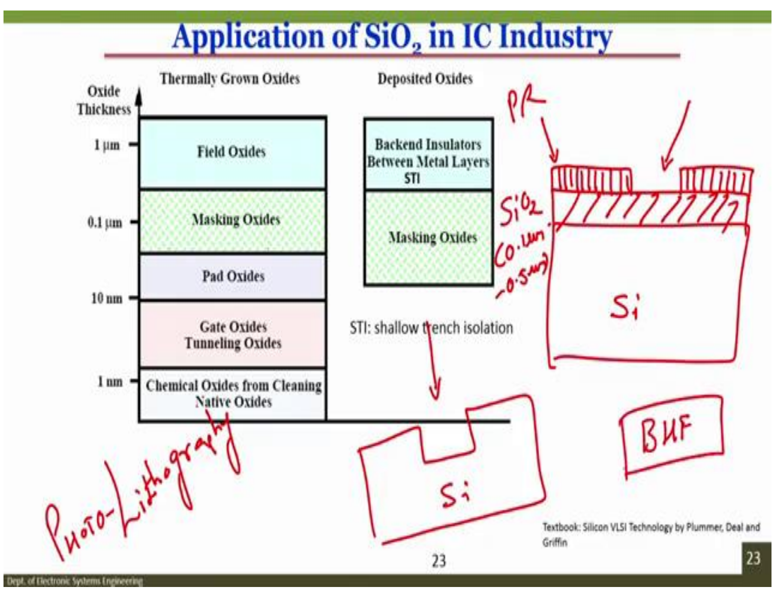

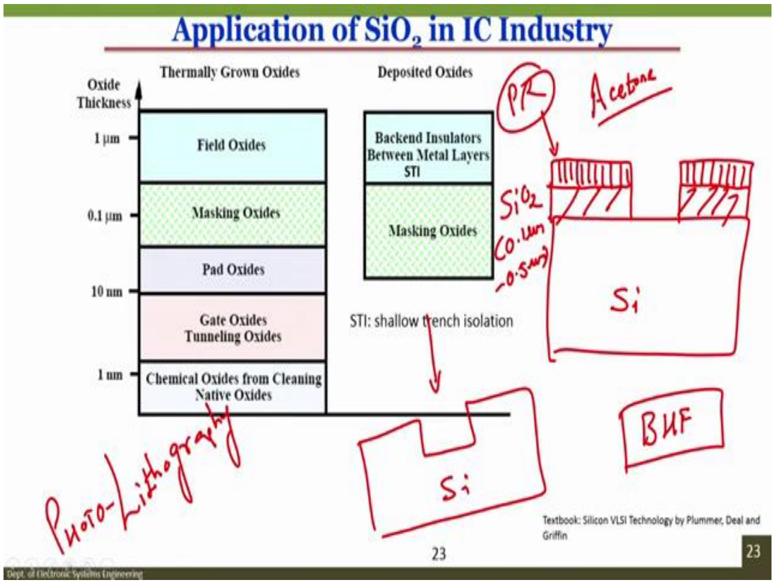

So for that, we will deposit silicon dioxide on this silicon wafer. We will deposit silicon dioxide on silicon wafer like this. And this silicon dioxide can be 0.1 micron to 0.5 microns. After depositing silicon dioxide, we will perform a process called a lithography, lithography. I will teach you lithography in the next module. Lithography using photo or photons is called photo lithography, photo-lithography.

So using the photo lithography process, what we will do, we will, we will protect silicon dioxide in this area. Do not worry about it how this has been done. Just understand that there is a photo resist, PR stands for photo resist I will teach you some time. And we will remove the photo resist from this particular area.

Now if I dip this wafer in BHF, BHF stands for buffer hydrofluoric acid. Buffer hydrofluoric acid will etch silicon dioxide. So, if I dip this wafer in BHF, what will happen, my silicon dioxide will get etched and if it is a BHF, silicon dioxide will get etch. Now, I will strip of the photo resist, I will strip the photo resist by dipping this wafer in acetone. Acetone is used for removing or stripping of photo resist.

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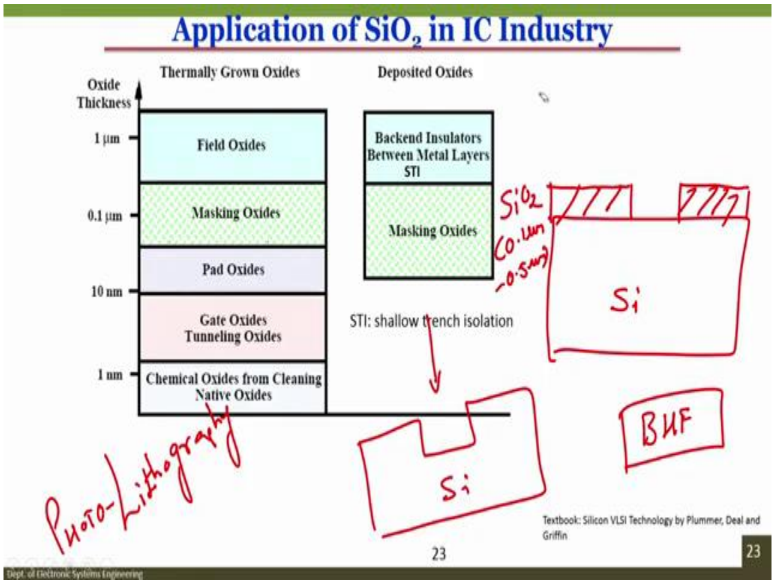

So when I dip the wafer in acetone, what will happen, photo resist will get stripped off.

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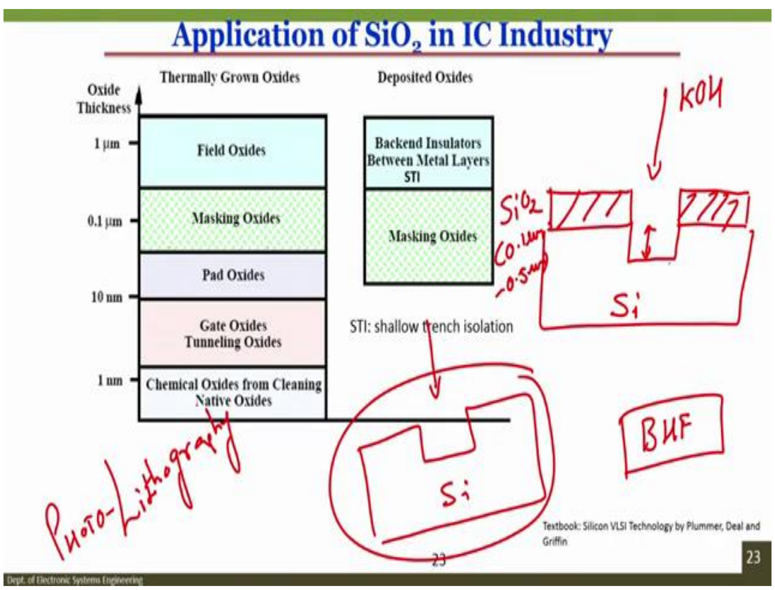

After this, I can dip this wafer in potassium hydroxide. What will happen? Silicon will start etching, but silicon dioxide will not get affected. Why it will not get affected? Because KOH cannot etch silicon dioxide. So if you see the screen, what do you find is, if I dip the wafer in KOH, then I will get this kind of etching. What do we want? We want this pit in silicon.

So after we get the required depth, we will stop, we will take out the wafer from KOH, rinse it with DI water, dry it and then dip this wafer in BHF.

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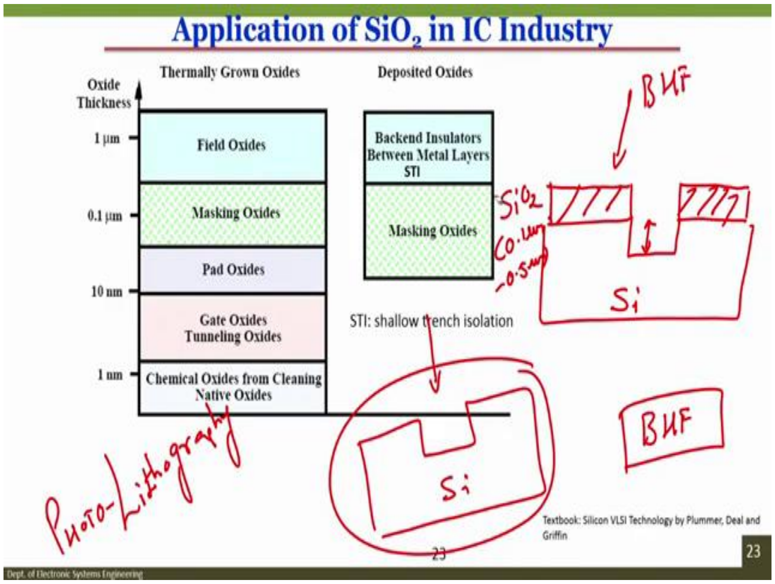

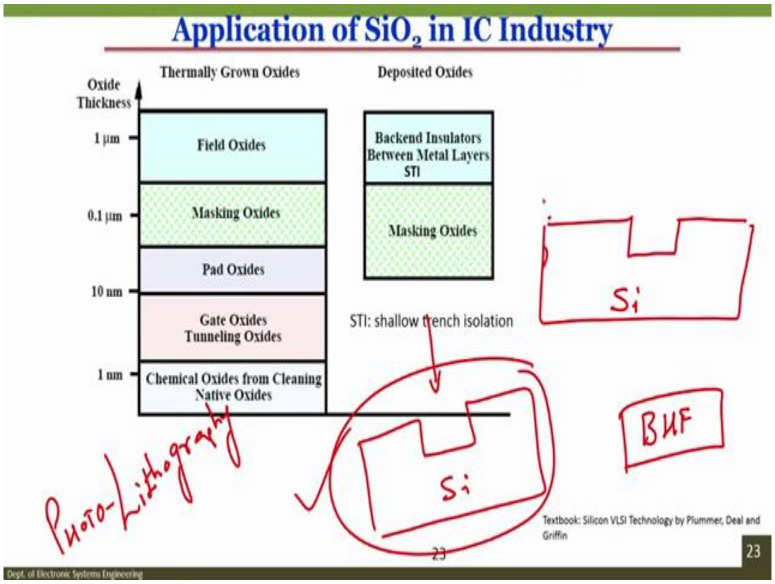

If I dip this wafer in BHF, what will happen? Silicon dioxide will get etched. And once silicon dioxide gets etched, we will get this pattern but what happens? Like what was the role of silicon dioxide here?

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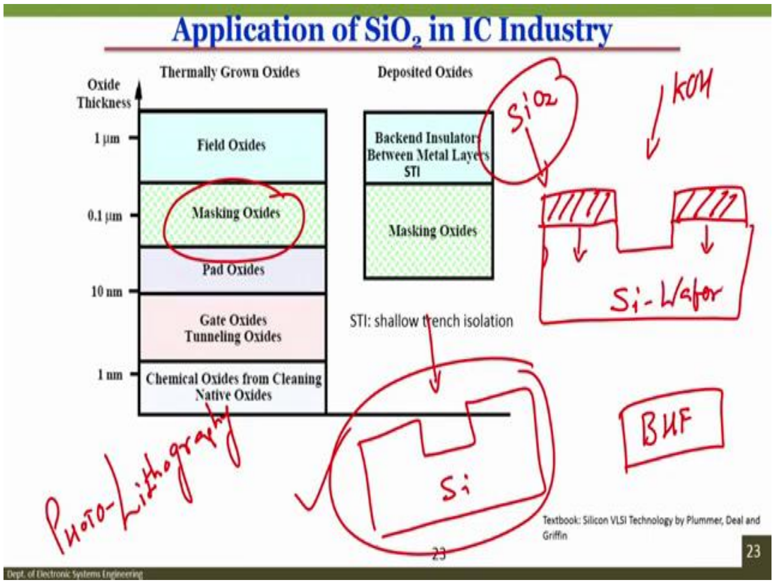

Role of silicon dioxide if you correctly understood was to protect this particular area, or I should draw the arrow in opposite direction. I can see that silicon in this area is not affected when I dip this wafer in KOH. So what was getting affected, where the silicon dioxide was not there, this area. This area, where the silicon dioxide was not there, it got etched.

That means, this silicon dioxide will act as a masking oxide, it will act as a mask through which the KOH will not penetrate and the silicon dioxide will act as a mask for silicon wafer, it will act as a mask for silicon wafer. So that is the role of masking oxide.

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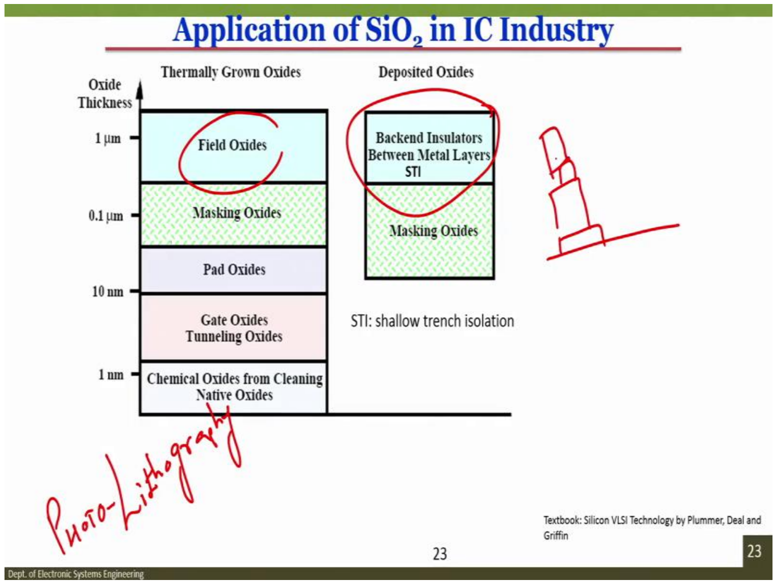

And then, comes the field oxide. Field oxide is when you want to use a thicker silicon dioxide for, for generating the fields. Again, we will discuss it at some point of time, if the time permits. We can also use the silicon dioxide as a field oxide. So another role of the oxide is also in the backend insulators between metal layers.

So, you have a metal layer, then you have to insulate some part of it and you grow another metal, again insulate some part of it, grow another metal, so you, you can do that on the backend side of the micro-electronics chip where you can use this insulator between two metals.

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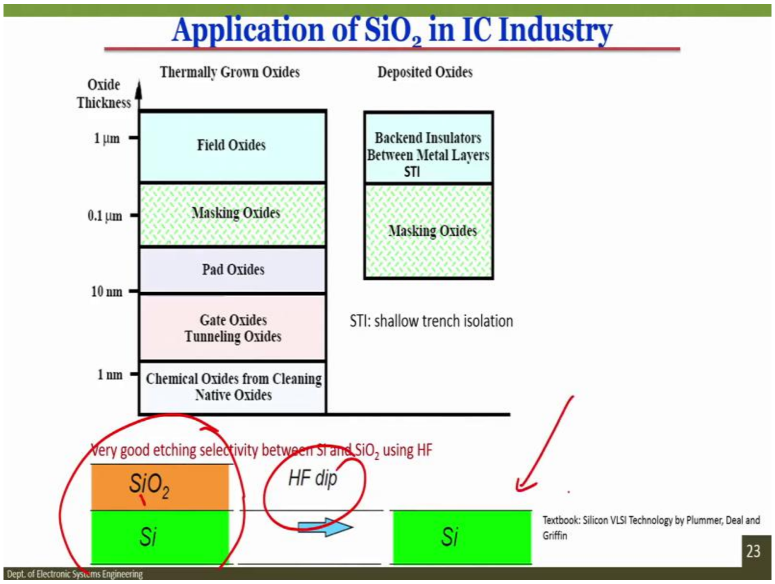

So having said that, how this silicon dioxide is useful we have seen a few examples but like I said, that if you have a silicon dioxide on silicon wafer, and you dip in HF which is hydrofluoric acid, then silicon dioxide will get etched and only silicon wafer will be left.

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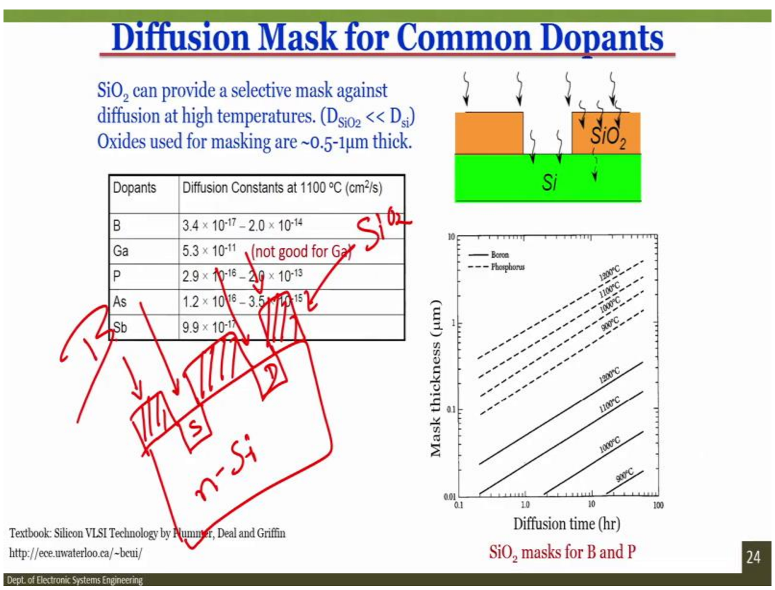

So, in another way, if you want to see, then you have source and drain. How this source and drain are created? Source and drain are created by doping impurities inside the silicon wafer. So, how to dope this source and drain inside the silicon wafer? Again by using the SiO2, so I have SiO2 here, then I have SiO2 here and here.

How we pattern this? Using photolithography, we will see photolithography in the next module do not worry about it. So this has silicon dioxide patented on silicon wafer. Now what I will do is, I will dope this silicon, because here SiO2 is not present. With let us say boron, if it is n type silicon, I will dope this silicon with boron. So what will happen, I will form source and drain.

So, in this case, where I am doping the silicon with boron, this boron doping, will not get passed through or the boron impurities will not get passed through silicon dioxide. Silicon dioxide will act as a mask for common dopants. What are the common dopants, either they are n type dopant or they are p type dopant, it can be boron, gallium, phosphorous, arsenide, antivenin and a lot other dopants are there.

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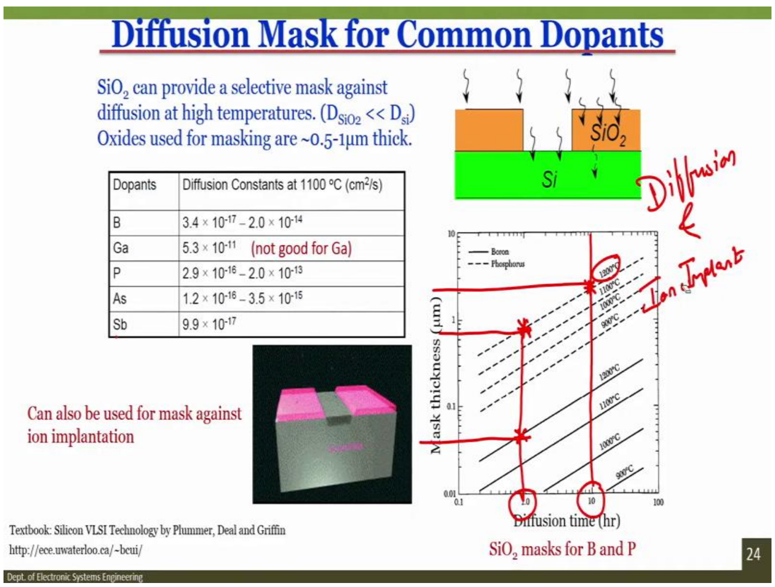

So, now another very important point is that what is the temperature that is required for doping a particular impurity. So if you see that, if I want that diffusion time should be close to let us say 10 hours and if I draw a line like this, then and the temperature, and it is a phosphorous material and the temperature is about 1200 degree centigrade, then I require how much silicon dioxide, I require close to 1.5 micron silicon dioxide or close to 2 micron silicon dioxide.

However, if I want the same to happen at 1 hour, that means I want to diffuse the phosphorous at 1200 degree centigrade, inside a silicon wafer for 1 hour, then what I get, what I want? I want a silicon dioxide which is close to 0.8 micron thick, 0.8 micron. But in case of boron, if I want to diffuse boron into silicon, and again the time is 1 hour, and the temperature is 1200 degree centigrade then you can see here that you require of silicon dioxide which is close to 0.05 micron, or 500 nanometer.

So this chart, or this table, this plot helps us to understand what should be the thickness of silicon dioxide that can be used as a mask for the common dopants depending on the diffusion time and depending on the temperature for that particular dopant. Let us go to the next slide. So you can, you can see here, can also be used for mask against ion implantation. See there are two techniques for diffusing the impurities; one is called diffusion and another is called ion implantation.

So, the SiO2 is not only using the mask against diffusion, but it can also be used for iron blending, while iron in blending the dopants into the silicon.

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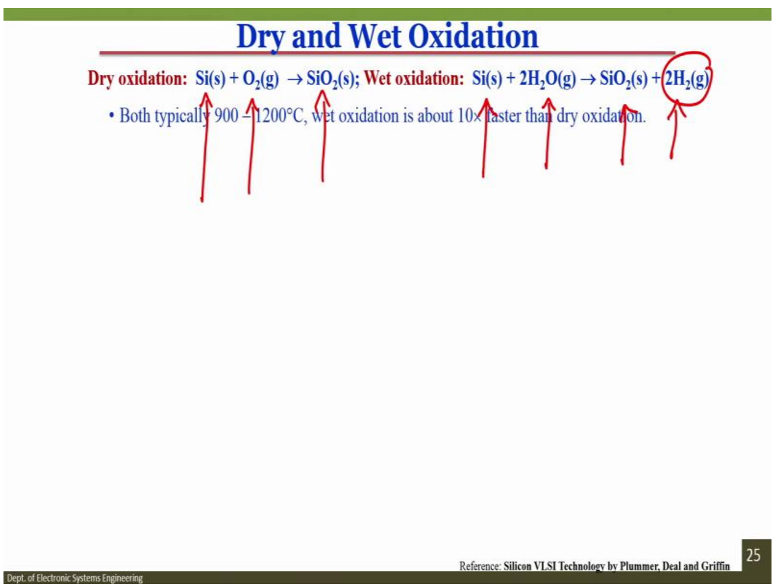

Now, like I said, there are two different techniques for etching, dry and wet same thing there are two different techniques for growing the silicon dioxide on a silicon wafer. One is called dry oxidation and another is called wet oxidation. Let us see dry oxidation, see silicon wafer at a high temperature when reacts with oxygen forms silicon dioxide and if it is wet oxygen, then what do we do? We have silicon wafer, we pass the water vapor on to the silicon wafer, the O2 reacts with silicon to form SiO2 and 2H2, 2H2 will be the gas that can come out from the furnace.

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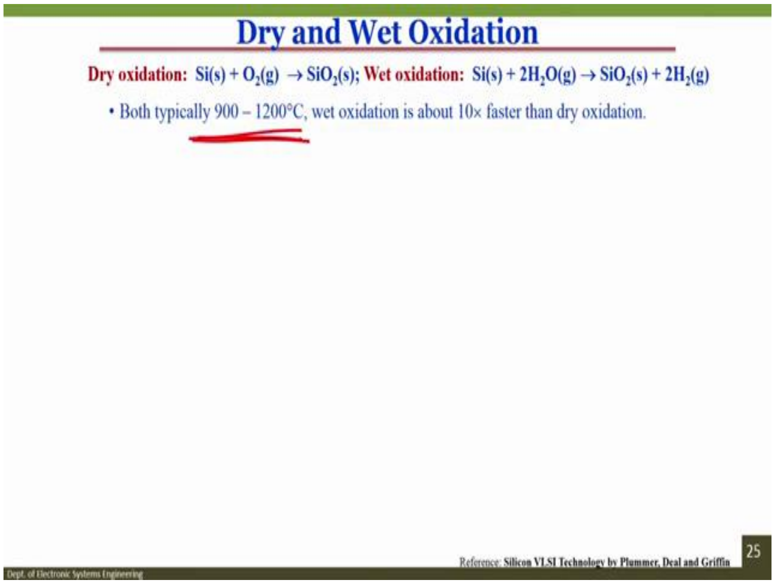

So, to do that, first is that the temperature require for both, dry and wet oxidation is closed, or is in between 900 and 1200 centigrade that is the temperature. And when you compare the reaction time or the growth time, then the wet oxidation is 10 times faster than dry oxidation.

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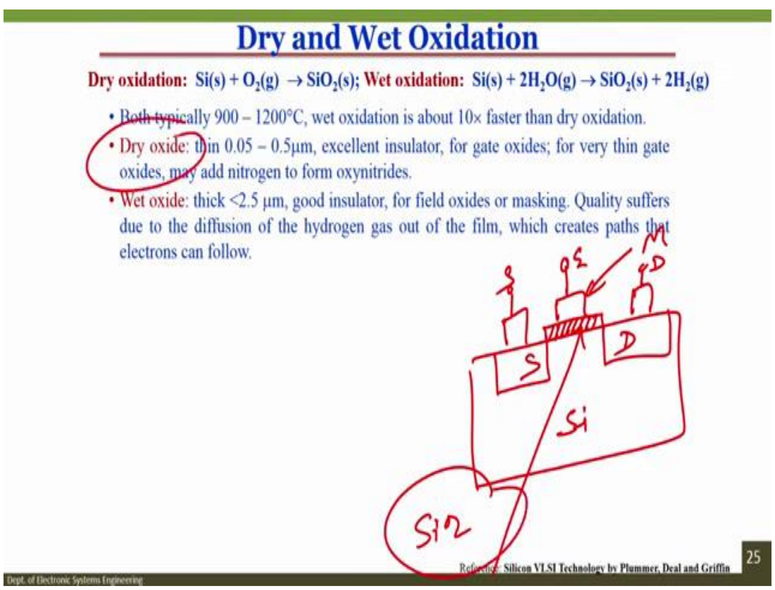

Another very important point is in dry oxidation the film thickness is from 0.05 to 0.5 micron. It is an excellent insulator for gate oxides. That means the one that I was showing you early, that when you have a MOSFET, you have a source, you have a drain, you have a silicon wafer and you form, want to form a gate oxide on which you can again form the gate.

This is your metal, this is your gate, again this is your metal, this is your metal for drain, for source then this particular oxide which is your silicon dioxide should be generally a dry oxide because it will give an excellent insulating property when you are using silicon dioxide as a gate oxide.

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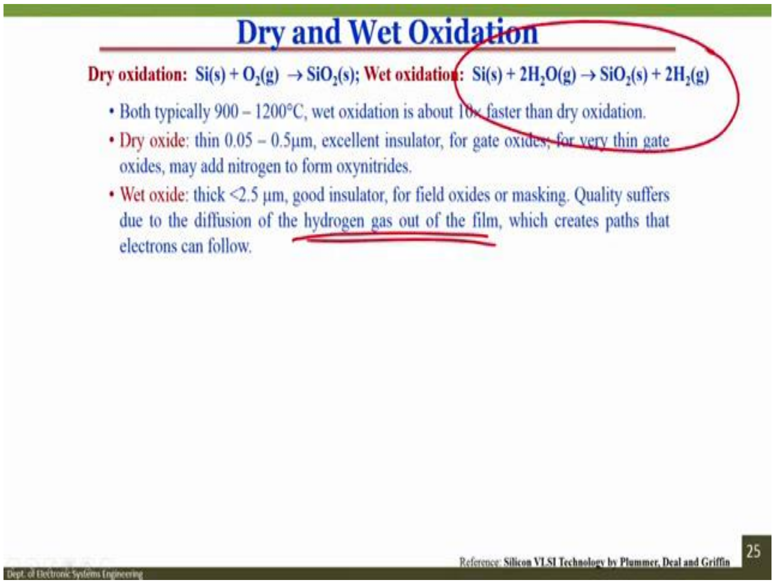

While for the wet oxide, we can have a thick but less than 2.5 microns. It is a good insulator for field masking or field oxide or masking oxides. But the quality of this oxide suffers due to the diffusion of hydrogen gas out of the film. You can see here, this particular reaction that you have Si plus 2H2O, 2H2O which reacts and forms SiO2 and 2H2. So, when the hydrogen comes out or diffuses out of the film, the quality of insulating material degrades. So if you see, this will create what will create path for electrons that can flow through that.

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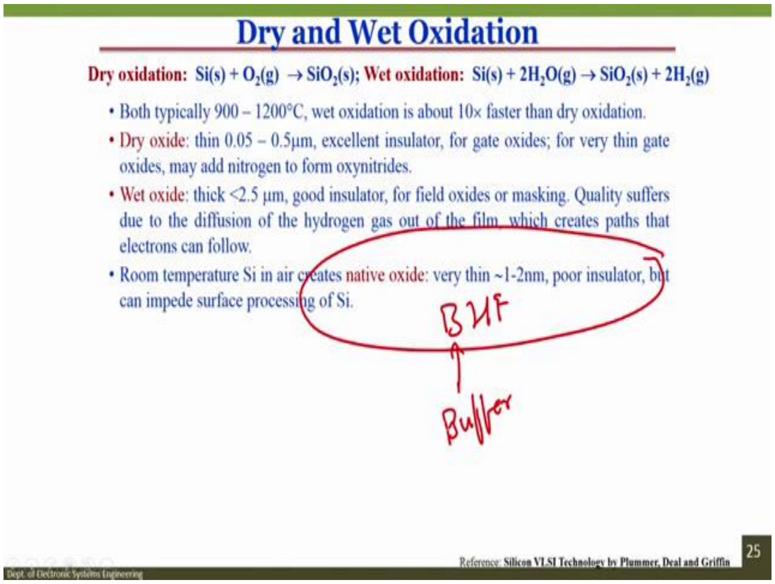

So room temperature silicon in the air creates a native oxide, we have seen that example also which is poor insulator and can impede the surface processing. That is why, what we have to do before we start using the silicon wafer, we have to dip the silicon wafer in BHF, buffer hydrofluoric acid. This is buffer, buffer hydrofluoric acid.

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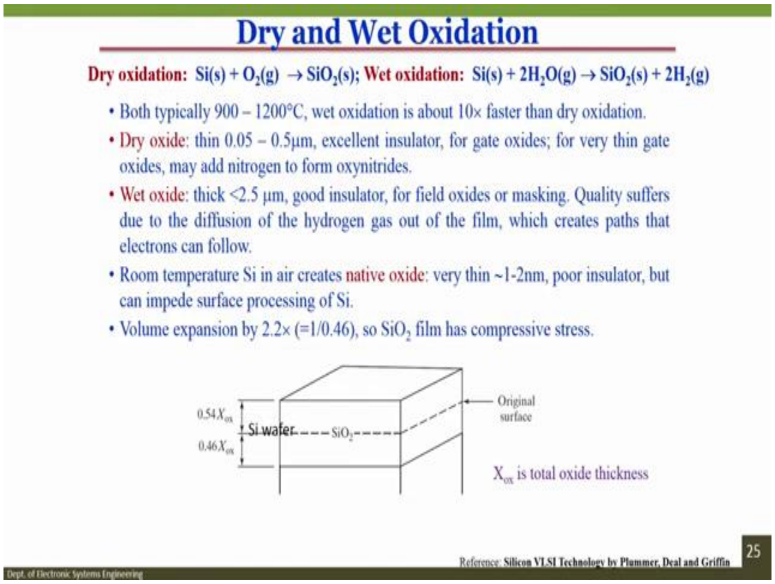

And if you want to understand how the volume expansion occurs, then this is the formula.

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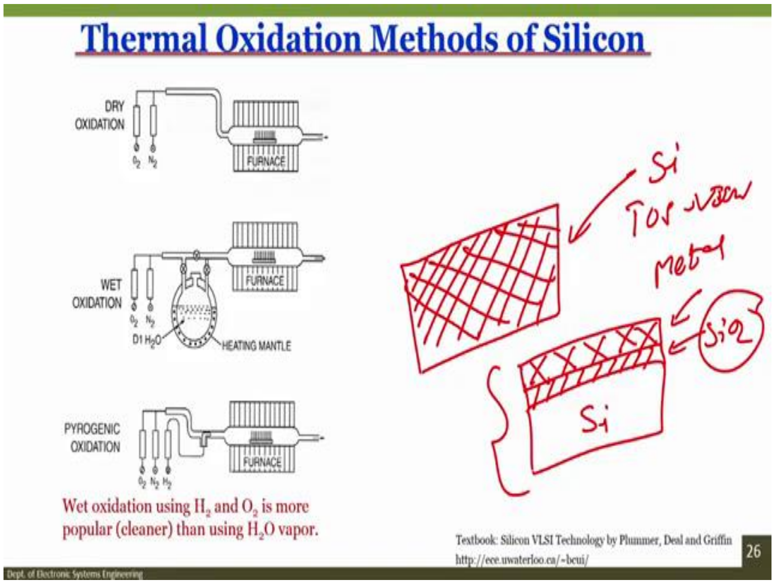

So, there are three types of oxidation technique; one is dry oxidation, another is wet oxidation, another is pyrogenic oxidation. Now you will again ask why we have to learn silicon and oxygen and oxidation and other techniques. The reason is that, we will form a chip, that is quoted with a metallic layer and base can be silicon, but if I deposit, this is the top view, and this is the cross-sectional view. If I deposit metal on silicon, then it is a short, because silicon is a semi-conductor.

That is why, what I will do is, this is metal. You understand these checks are metal. So what I have to do is, I have to form silicon dioxide and on silicon dioxide, I have to deposit metal. So this is my metallic layer, this is silicon dioxide. And this one with the base material is silicon. So if I show you that you use this chip for EG measurement, or other measurements, you will ask a question what exactly is the substrate? We say silicon. Then the question is how silicon is fabricated, that is why we took the class on silicon fabrication.

The next question is, if I want to have insulating material between silicon and metal, what should, what kind of insulating material I can use? So we are discussing silicon dioxide and its growth process. So everything that I will be covering as a part of this particular module, and if the remaining modules are related to the EG, electro design, as well as the fabrication techniques, that will be used for understanding some of the properties of the brain. And that is why it is very important to understand all these details before we go into the application part.

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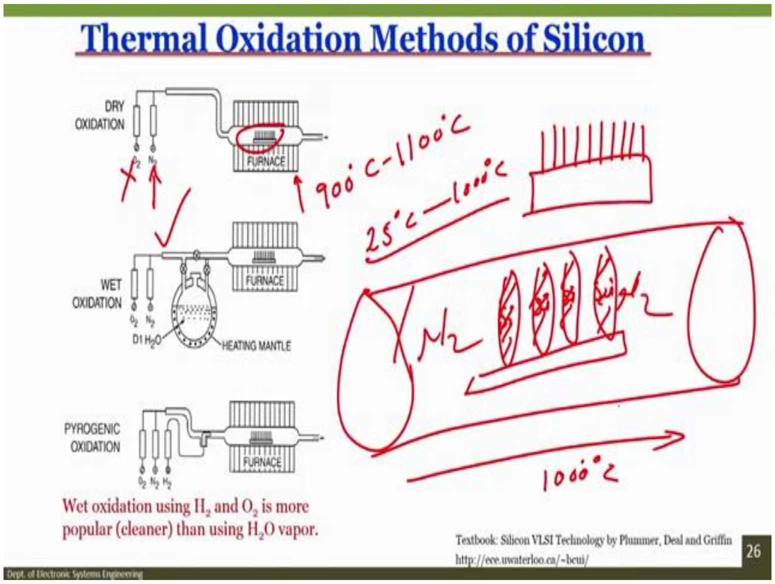

So, coming back to your thermal oxidation, like I said if the first one is dry oxidation, in this, you have oxygen and you have nitrogen. Now what is the role of nitrogen? You see what you see here is a furnace. Furnace, what is the temperature, we have seen, it should be 900-degree centigrade and 1100 degree centigrade. This will be temperature, anywhere between 900 and 1100 degree centigrade.

So if I heat that (temp) heat the furnace at 900, or between 900 and 1100 degree centigrade and this, this lines that you see, like this, you see here, this one, these are silicon wafer. So I have, this is like this. Silicon wafer, in a slot it is holding this silicon wafer and this whole thing is within the furnace, very bad drawing, like this. This is a horizontal tube furnace. You can see, the tube is in the horizontal direction. Horizontal furnace, these are silicon wafers.

Now this temperature is 1000 degree centigrade. Let us assume that this temperature is 1000 degree centigrade. If I start oxygen, while the furnace is heating, then you will not get an optimized silicon dioxide on these particular wafers. So what is the role of nitrogen? Initially when you are heating up the furnace from room temperature, let us say, 25 degree centigrade to 1000 degree centigrade, you need to make sure that no silicon dioxide is growing on silicon wafer.

And that is why, what we will do is, we will close the oxygen supply and we will only have nitrogen gas into the furnace. So if we purge nitrogen gas inside the furnace, then nitrogen being an inert gas, everything is end to, there is no silicon dioxide on the silicon wafer that is inside the furnace, while the furnace is heating on. So initially nitrogen is, is purged in the furnace.

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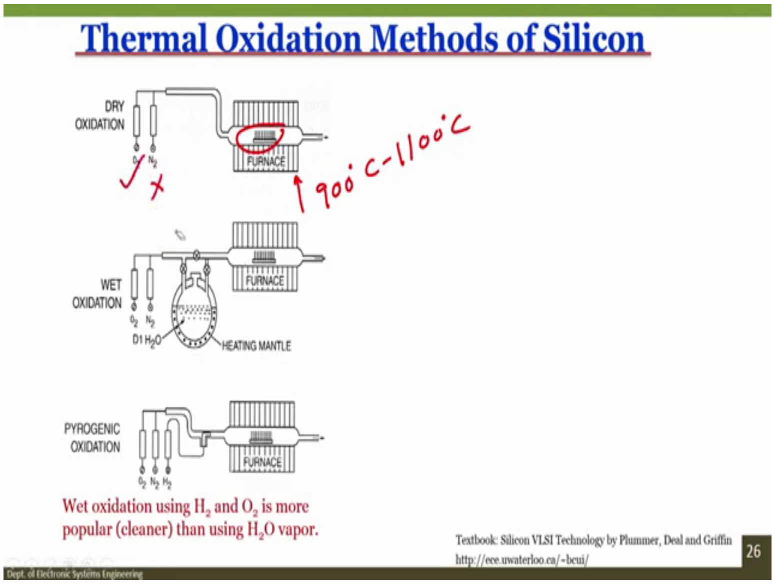

And once you, once the furnace temperature is achieved, then nitrogen is switched off and oxygen is switched on, in that case, what will happen, oxygen will start reacting with silicon to form silicon dioxide. Now, let us say, let us understand what happens when it is wet oxidation.

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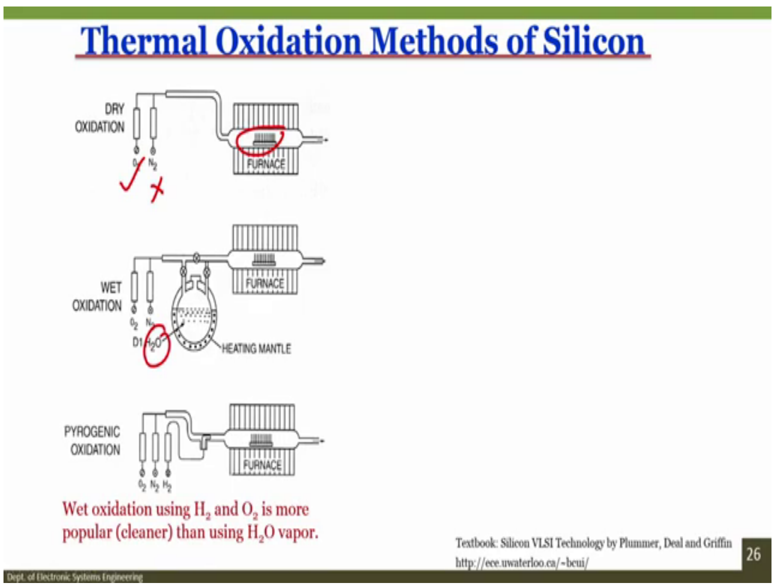

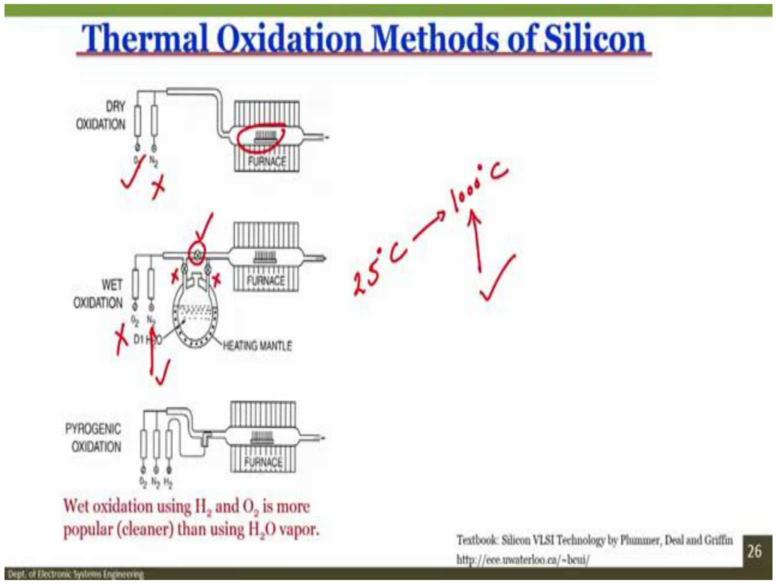

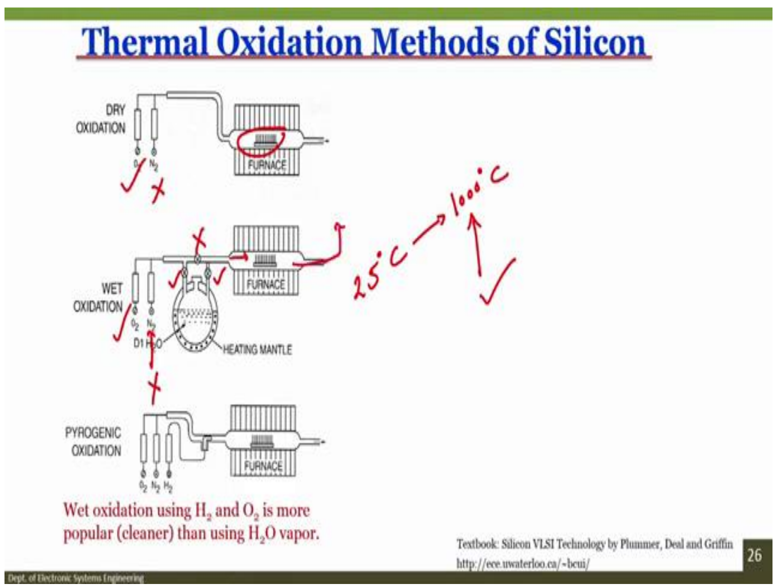

In wet oxidation, you have a heating module and you have something called a bubbler, inside which you can have water. And when the water heats up, there is a water vapor that is created. Initially, again, you what you will do, you will close this valve, close this valve, open this valve, open the nitrogen valve and close the oxygen valve when the furnace is ramping up from 25 to 1000 degree centigrade.

Once the temperature of the furnace is 1000 degree centigrade, once we achieve this temperature, then what we will do, so initially only nitrogen is allowed to flow inside the furnace. You can see that if I open the nitrogen valve, and if this valve here is open, then the nitrogen can pass through furnace. So initially when it is ramping up, we will open nitrogen. Once we receive the, once we get the, once the furnace is at 1000 degree centigrade, then we will switch off the nitrogen.

We will switch on the oxygen valve, I will open the oxygen valve, will open this valve, will open this valve and we will close this valve. So what will happen, oxygen will pass through the bubbler and the, it will create, it will take the water vapor and this water vapor will pass into the furnace. That means H2O in the gaseous form will pass through the furnace and silicon will react with this, with the H2O in a gaseous form which is water vapor to form silicon dioxide and 2H2 which is hydrogen gas, which can come out of this particular furnace. So, this is how the wet oxidation is, is done.

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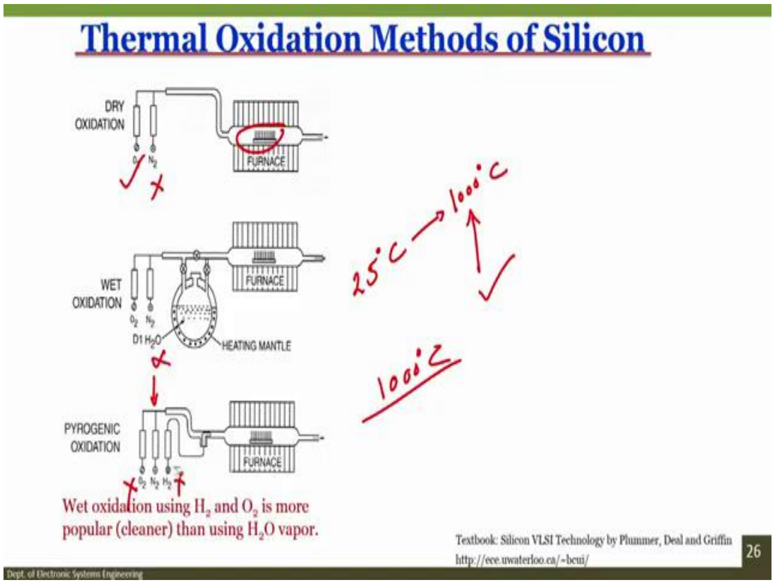

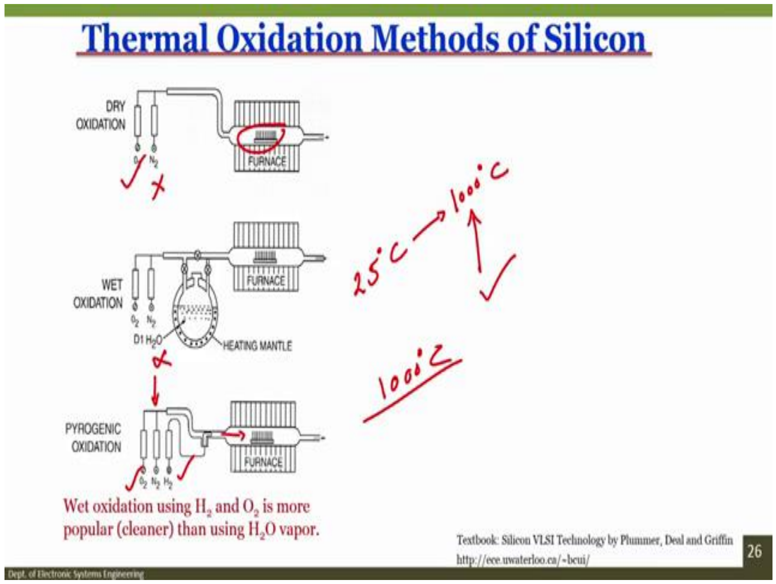

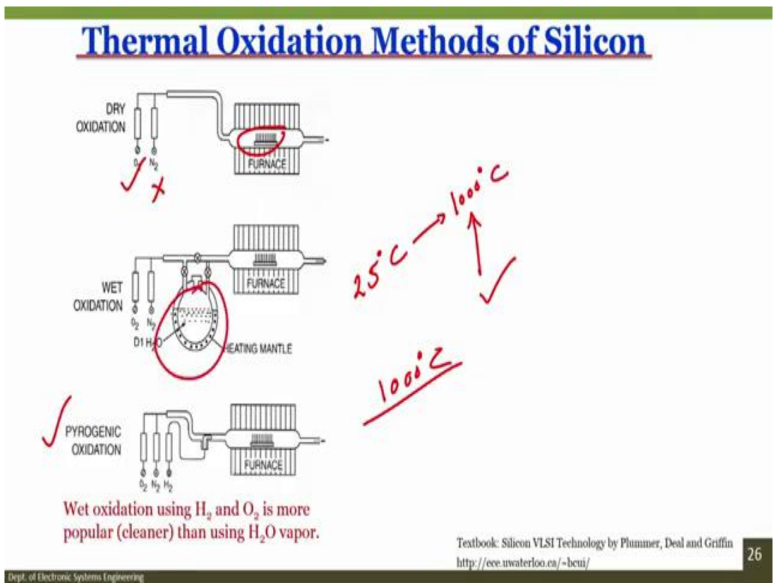

The final one is pyrogenic oxidation. In this case what we do, again initially you have only nitrogen open, H2 is closed, O2 is closed. Once that furnace achieves or reaches the required temperature, our example is 1000 degree centigrade, we stop the nitrogen valve and we open the H2 and O2 valve. So that H2, when H2 reacts with O2, it forms H2O. And that H2O goes inside the furnace, or purges inside the furnace to form the H2O2.

Wet oxidation H2 and O2 is more popular or cleaner than H2O. If you want to use wet oxidation, then it is better you go for pyrogenic oxidation, since you have a cleaner H2 and O2, rather than using the water and using the water vapor by the heating mantle and then carrying these with the help of oxygen vapor. So, so these are 3 techniques that are there with us for silicon dioxide growth.

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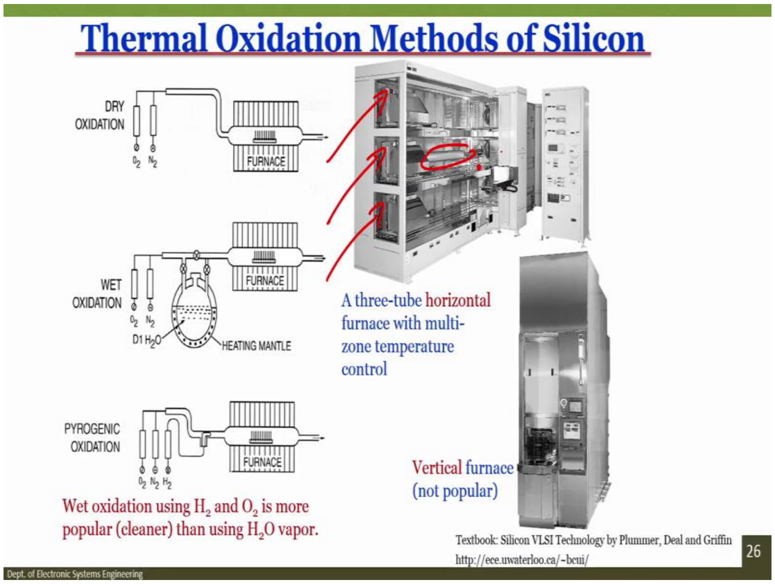

And if you see how the horizontal tube furnace looks like, you can see from this particular figure that you, there are 3 tube horizontal furnace. And then there is a vertical furnace where the vertical furnace is not that popular compared to the horizontal tube furnace. This is one, this is second, this is third, this is, here you can see that there is a tube which can be heated at a high temperature. And let us see the next slide, so that we can understand better.

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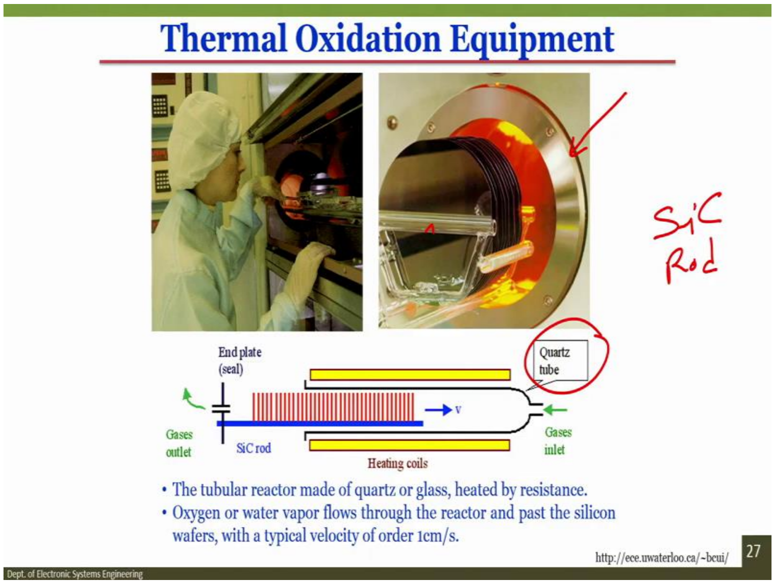

You can see here that the silicon wafers are being loaded inside the furnace. And here you can see that the engineer is loading the wafer using a silicon rod is called silicon carbide rod, not silicon rod, silicon carbide rod. So this wafer is pushed inside the furnace not directly touching the wafer holder, but by using the silicon carbide rod.

So what you have here is that tube that is used in horizontal tube furnace is made up of quartz. And you have a silicon rod to push the wafers inside. There are heating coils and it is heated by resistance. Oxygen or water vapor flows through the reactors and pass the silicon wafer and the typical velocity is order of around 1 centimeter per second.

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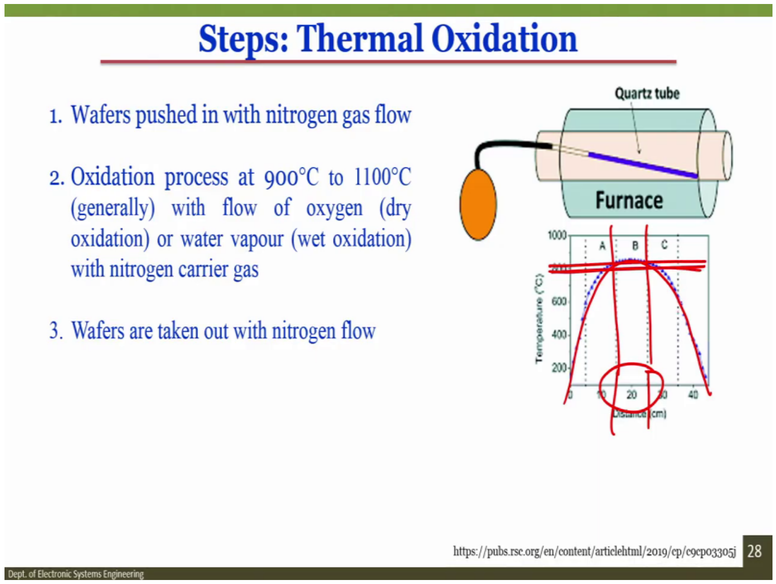

So, the steps would be wafers pushed into the nitrogen gas flow, oxidation process at 900 degree centigrade to 1100 degree centigrade with the flow of oxygen or whatever nitrogen carrier case, wafers are taken out with the nitrogen flow. This is how generally the ramping is done. And slowly and not ramping is done, this is the where the temperature is maximum, is in the centre of the wafer.

If the wafer is there of the furnace if the furnace is around 40 centimeter, 45 centimeter in length we will see that close to 15 and 25 you have the kind of an optimum temperature achieved. So this is the wafers should be placed.

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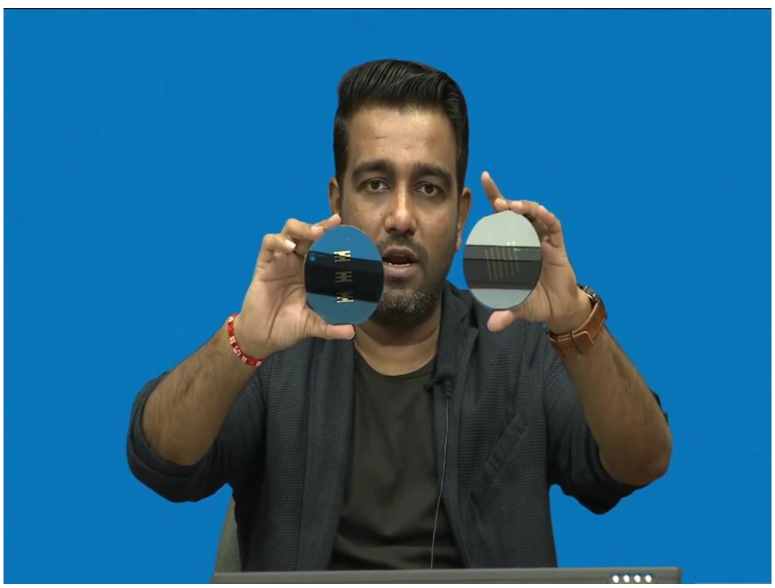

This is a photograph of a silicon wafer and silicon dioxide wafer, like I promised in the last class that I will also show it to you how the silicon wafer looks like. If you see my hand you will be able to see, this is the silicon wafer that is I am holding in my hand. If I am just rotating, tilting little bit, you will be able to see a greyish color. But if I have a silicon dioxide, I will show it to you, so compare, you will see here that the color is about purplish color. So you have a purplish color compared to the greyish color.

You can see here, I am tilting both the wafers so that you understand. You see here, this one, this one is grey. This is one is bluish or purplish. Why? Because this is a silicon wafer without oxide and this one is silicon wafer with oxide. Now let us see, what is back side of this wafer. We also learnt about single side polish and double side polished wafer.

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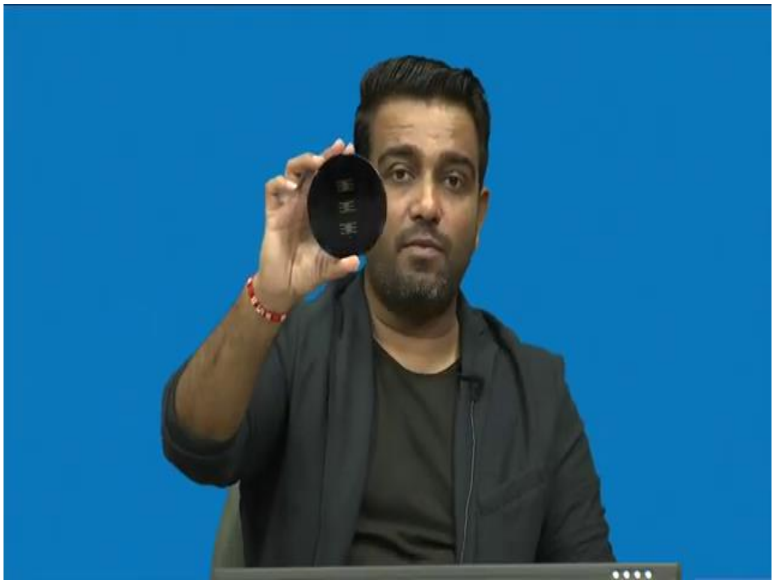

This one is single side polish. You can see the image of the hand or a finger on the silicon wafer. Can you see that? I will show it to you. You can see the reflection, reflection. Very clearly you can see the reflection. You can see, let us say if I put my finger here, you can see the finger also coming, the image of the finger.

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But if I show you the backside, you see nothing. This is a rough, rough area. So, the surface from which the front side is polished, front side is polished and the backside is rough, it is a single side polished wafer. It is single side polished wafer. You may get a wafer which is double side polished, which are mirror surface on both the sides, but this wafer that I am holding is single side polished wafer. This is rough surface, the front surface is smooth.

Now, let me also tell you that the way I was holding a wafer is not correct. We cannot use bare hand to hold the wafers. We must use tweezer we must use gloves and then only hold the wafer.

This is only for demonstration purposes that is why I was holding with my hand. Also we have discussed that other than silicon, we can also use glass, is not it?

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So, this is the glass wafer. You can see it is transparent. It is a glass wafer, but it is a wafer. It is a whole circular wafer. And what will be the thickness? This appears, what is the thickness, the thickness is close to 500 microns, 500 microns thick is whole silicon, or a silicon dioxide wafer or a glass wafer. On this glass wafer, we have patterns, certain things do not worry about this pattern right now.

The point that I was making is, you can also use a glass wafer instead of your silicon wafer. This is the glass wafer. So, depending on the application, you can change the substrate, these are substrates.

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And if you see the screen again, then what you will see is that this one is your silicon and this one is your silicon dioxide. When you grow silicon dioxide, this is silicon dioxide on silicon wafer. And this is just silicon wafer. So when you grow silicon dioxide on silicon wafer, since silicon dioxide is transparent, you will be able to see the change in the color of the wafer depending on the thickness of silicon dioxide.

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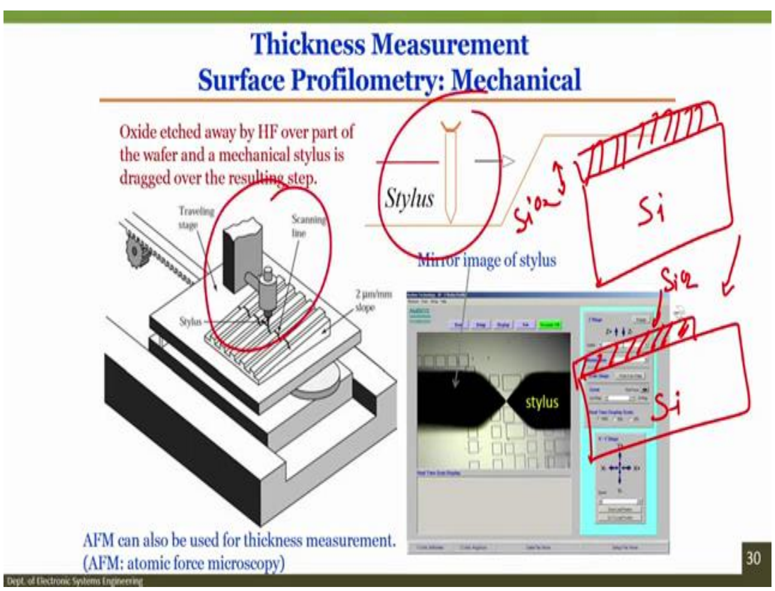

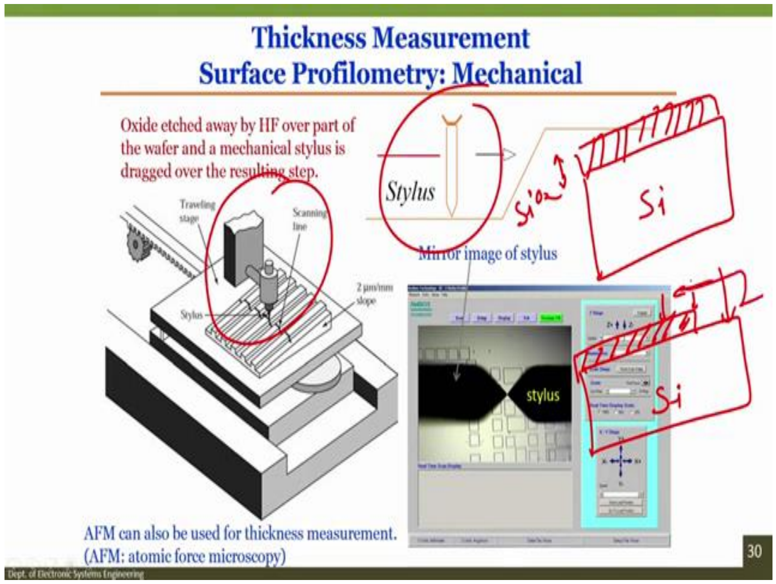

So there are two ways to understand, what is the thickness of silicon dioxide, one method is called surface profilometry, which is a mechanical measurement. And how does it work? So, in this case, I have a silicon wafer and I have silicon dioxide grown on silicon wafer. Deliberately I will, I will leave this space. I will not grow silicon dioxide in this area. And what I will then do is, that or let us see in another way.

If I have silicon dioxide everywhere like this and I want to know what is the thickness of this silicon dioxide, that is a question. Then in that case, I will perform a photolithography and etch silicon dioxide only in this area where other area silicon dioxide still is there. And then, I will use a stylus, you can see here, you can see here, I will use a stylus. Stylus is a diamond tip, with a diamond tip. And this diamond tip, I will scan it in this direction. So, it will come here, it will come here, so when, when this happens, what will happen, there is a, there is a step that is created.

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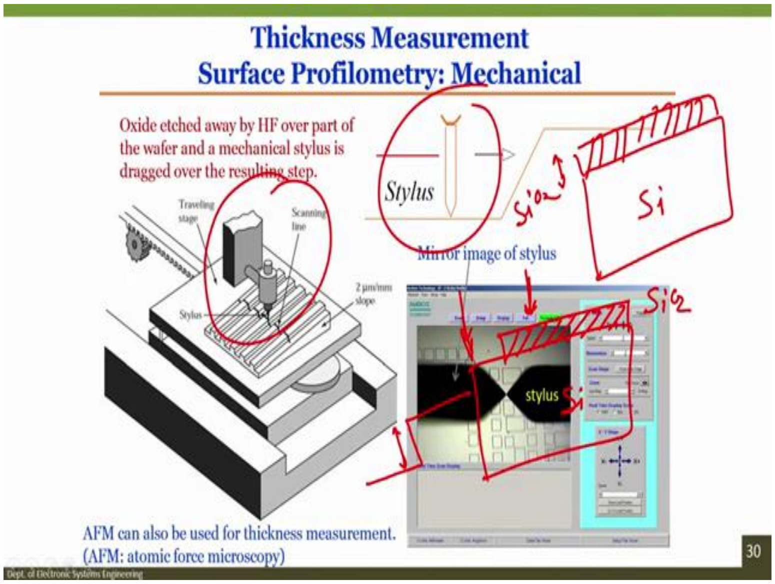

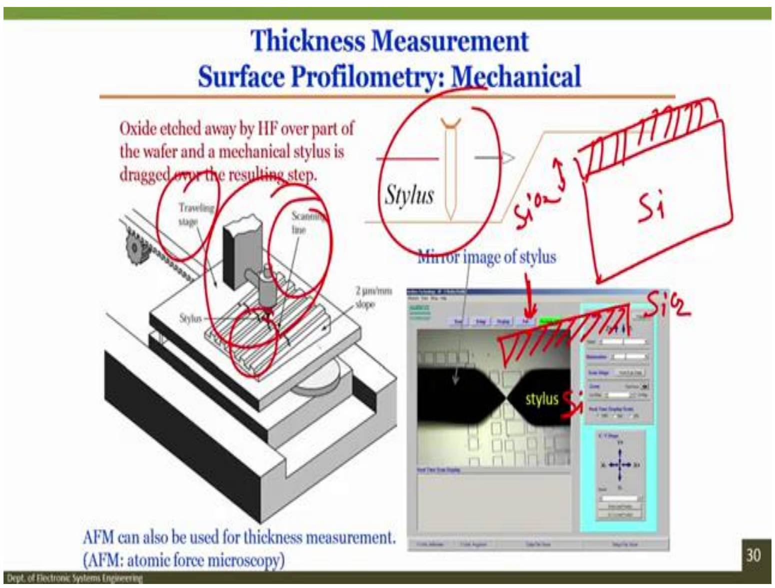

Let me again tell you, let me draw it little bit on the sides, so it is easier. I have a silicon wafer oxidized wafer. I am patterning this silicon dioxide using photolithography and then I am using a stylus to move across the silicon or scan this silicon wafer. What will happen, when it scans silicon wafer, from this end to this end, there is a creation of step. And this step will tell us what is the thickness of the oxide on the silicon wafer.

So same is shown with the, in the schematic. You can see here, there is a traveling stage, there is a stylus, there is a scanning line and it moves across the wafer and it will tell you the step or size or the height of the silicon dioxide on the silicon wafer.

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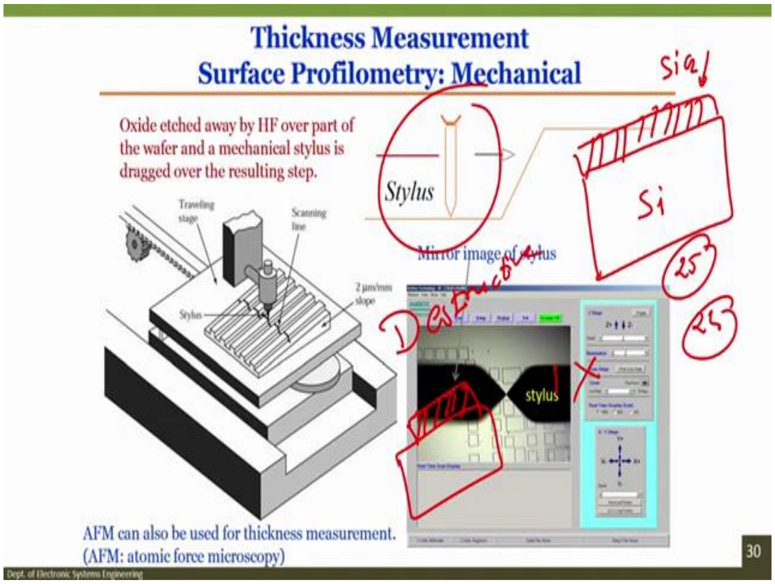

So, the disadvantage of this particular method is that this is silicon dioxide and I have let us say 25 wafers, so one wafer I have to sacrifice because in one wafer, I have to remove silicon dioxide from a certain space. And that is why this is a destructive type of technique. What it is called, destructive because it will destruct the silicon dioxide on the silicon wafer and that is why I will left with over 24 wafers.

Because I had to remove silicon dioxide from silicon to understand the thickness of the silicon dioxide. So when you see this kind of systems, it will help you to understand what is the thickness of the silicon. This is also is called alpha step profilometer. It is also using a similar technique which is used in atomic force microscopy. So there are multiple ways of using the similar kind of applications to understand the roughness of the film.

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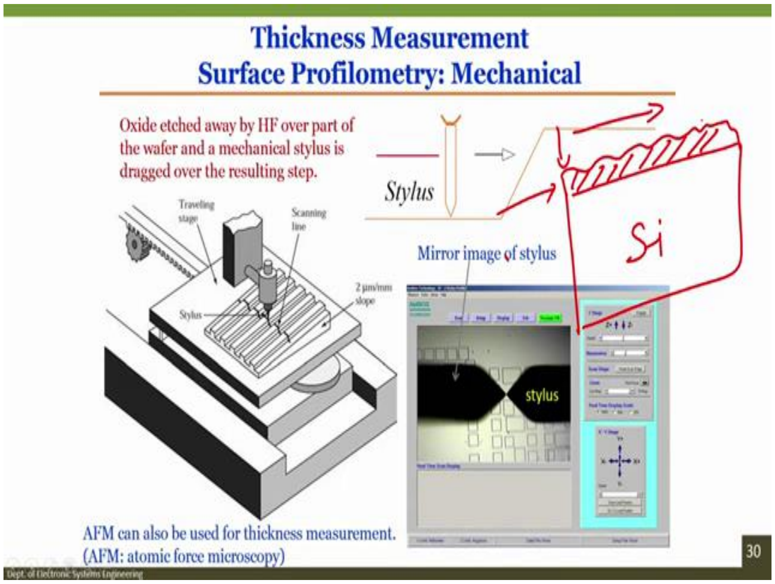

The second idea is that, if you see the screen, if I have the wafer, I am drawing the wafer on the screen, and if the, if the silicon dioxide as I am growing is uneven, like that, how would I know what is the roughness of this silicon dioxide? This is silicon dioxide. So to understand the roughness of the film, I will, I will scan this film again with a stylus profilometer and I will understand what is the roughness of the film. So this can be used for many applications.

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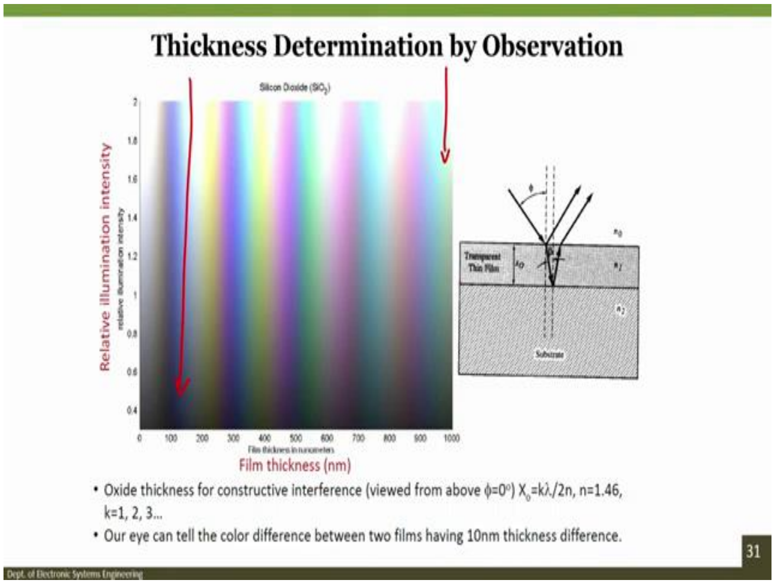

Now, the second way is by observation. It is a crude way of determining what is the thickness of silicon dioxide as we can see the relative illumination intensity would change depending on the thickness of the film. If we have a film which is about 100 nanometer, then the reflection would be like this, compared to a film which is 900 nano-meter or 1000 nano-meter which will look like dark green.

So, it is very very important to understand the, silicon dioxide thickness and this is an extremely crude method to understand what is silicon dioxide thickness. The right way is either using alpha step profilometer which is your stylus monitoring, or you use the another way which is called the ellipsometer.

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Film Thickness (Å)	Color of Film (those shown are only indicative)
500	tan
700	brown
1000	dark violet to red violet
1200	royal blue
1500	light blue to metallic blue
1700	metallic to very light yellow-green
2000	light gold or yellow - slightly metallic
2200	gold with slight yellow-orange
2500	orange to melon
2700	red-violet
3000	blue to violet-blue
3100	blue
3200	blue to blue-green
3400	light green
3500	green to yellow-green
3600	yellow-green
3700	green-yellow
3900	yellow
4100	light orange
4200	carnation pink
4400	violet-red
4600	red-violet
4700	violet
4800	blue-violet
4900	blue
5000	blue-green
5200	green
5400	yellow-green
5600	green-yellow
5700	yellow to "yellowish" (at times appears light gray or metallic)
5800	light orange or yellow to pink
6000	carnation pink
6300	violet-red
6800	"bluish" (appears between violet-red and blue-green - overall looks grayish
7200	blue-green to green
7700	"yellowish"
8000	orange
8200	salmon
8500	dull light red-violet
8600	violet
8700	blue-violet
8900	blue
9200	blue-green
9500	dull yellow-green
9700	yellow to "yellowish"
9900	orange

But before we go to ellipsometer, let us see that the thickness determined by observation right from 500 angstrom all the way to 999, 9900 angstrom, we can see that how the color changes.

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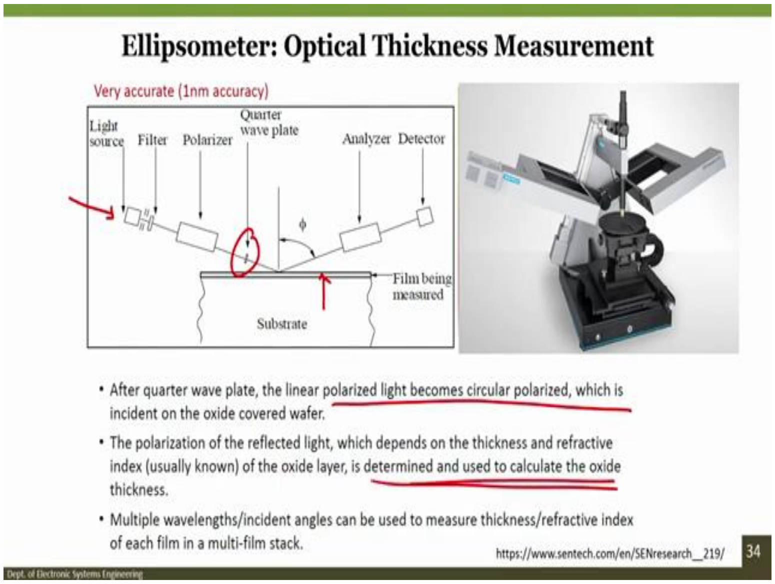

And we talk about alpha ellipsometry then you can see here that it will help to understand the thickness of the film without destructing the film, because it is based on the, on the reflection of the light source from the substrate on to the detector. And there are several stages inside the ellipsometer. Right from filter to polarizer to quarter wave plate, analyzer and detector.

And after quarter wave plate, the linear wave, so when I, when you incident the light, then after this quarter wave plate the linear polarized light becomes circular polarized which is incident on to the oxide cover wafer, which is this one. The polarization of the reflected light which depends on the thickness and the reflective index of the oxide layer is determined to use to calculate the oxide thickness.

And finally multiple wavelengths or incident angle can be used to measure the thickness of the, of the each film. The only disadvantage here is that, some of the metal films cannot be, they cannot be determined. So that was the end of this particular module. In the next module, we will see how photolithography can be used. Photolithography is a heart of microfabrication technique.

And if you learn photolithography, then you can design not only sensors, not only transcriptors, not only MOSFETs but lot of other applications, a lot of other devices as well, whether it is biomedical application, whether it is micro-electronics application, or it is pure mechanical engineering application where you want to determine or design and fabricate actuator, you can use micro-fabrication or photolithography technique.

So we will see this technique in the next module, till then you understand the importance of silicon dioxide on silicon wafer. If you have any questions, you can always ask in the forum. Doctor Mahesh will help you out to understand all the equations. We also have, we will all help you out to understand the, what are the possible solutions to questions if any. Till then you take care and I will see you in next module, bye