Advanced Neural Science for Engineers
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Indian Institute of Science Bangalore
Lecture 07
Piranha Cleaning of Silicon Wafer

Hello everyone, welcome to this particular lecture, we have seen the last lecture what are the process for fabricating or creating a silicon wafer, whether it is Czochralski technique which we call CZ technique or float zone technique which is called FZ technique. So, Z or Z is same thing which is FZ technique or CZ technique.

Now, there were advantages and disadvantages or advantages and limitations of CZ technique that we can have larger quantities of silicon wafers or a boule actually and from the boule we were slicing the boule to form the wafer. So, but the point is the FZ technique because the float zone there is a melting zone between the seed in the feed crystal the impurity is less.

The impurity which is unintentional impurity in the wafer would be less and that is why the cost is a little bit on higher end, because the way the technique is used you cannot have a larger like lot of boules like CZ technique. So, once you have a wafer, which is the substrate like I said the substrate can be any material on which you grow layers after layers pattern it to form a device.

Whether it is a device, it is a chip, is a sensor, there are multiple terms. If a chip I say then chip can integrate or chip can consist of multiple devices. We have seen one chip which has an electrical sensor which has interdigitated electrodes, micro heater and surrounding the device, thermistors or temperature sensors, but if you just say of pressure sensor or force sensor it is one sensor.

So, a bio chip or a chip. Now, bio chip when we use or bio sensor per se, then we use that particular sensor to or for biological applications. For example, you want to measure protein from a sample or you want to let us say you want to measure the bacteria or capture the bacteria from the sample then the sensor that is used for such application we can call them biosensors or we can call it bio sensors.

Now, when you have silicon like we discussed in the last lecture, when we have silicon, silicon is a semiconductor. So, if you deposit any material on silicon when you say any material that means any metal on silicon, then there will be a semiconductor metal junction contact. But that is what we do not want, we want just silicon to be used as a substrate because of its unique properties.

What are unique properties? That we can create a diaphragm we can etch the silicon using different techniques one with micro machining, in micro machining, there are 2 which is bulk micro machining and surface micromachining. We will look into that at a later stage. But the point is that there is an advantage of using silicon also there are processes by which we can form transistors using silicon as a substrate.

Now, for the devices if you want to use silicon and if you want to pattern a metal on silicon, then it is important to oxidize the silicon wafer that means it is important to have an insulating layer. Now, why insulating layer? Because there is a silicon which is semiconductor on which there is an insulator which is the silicon dioxide and on that if you deposit metal then there is no short circuit. So, there is a reason of using the metal when you want to use metal on silicon or metal on oxidized silicon, the reason of oxidation is to form the oxide layer.

Now, you can grow the oxide layer or you can deposit the oxide layer there is a difference. When you grow that means there is some kind of reaction that occurs with silicon wafer so, that silicon dioxide grows. But when you want to deposit silicon dioxide that means there should be some source material, there is a substrate which is a silicon wafer on which the layer should get deposited. So, these are 2 different techniques, what we were looking in the last lecture and that was on growing of silicon dioxide and growing of silicon dioxide requires the thermal oxidation technique.

Now, if you want to grow a silicon dioxide on silicon using thermal oxidation technique, then we should know that what kind of thermal oxidation techniques are there, is that only one thermal oxidation technique or within thermal oxidation technique there are different ways of growing silicon dioxide.

So, what we have seen is that there is a dry oxidation and there is wet oxidation. Dry oxidation will form a better thin layer of silicon dioxide cannot form thick layer of silicon dioxide. And the way the silicon dioxide is grown from silicon using dry oxidation is by using oxygen as a carrier gas not as a carrier gas, oxygen as a reactant gas and nitrogen as a carrier gas.

So, we will see that how it works? But the point of the chemistry is that you have oxygen plus you have silicon. So,

$$Si + O_2 \longrightarrow SiO_2$$

as simple as that. But the limitation of this is the thickness of the silicon dioxide. So, if you want to improve the thickness of silicon dioxide, you want to have a fastest silicon dioxide, you have to go for wet oxidation. So, now in wet oxidation, what we need to do? We have silicon plus H_2O which is in the vapour phase. It is a vapour, water vapour gives SiO2 plus H2, but you have to balance the equation, is not it?

So, oxygen or silicon + 2 H_2O gives SiO_2 + 2 H2O. Now, hydrogen comes out as a bypass, the bypass or a byproduct of it. So, when hydrogen will come out, there will be the path for silicon electron transfer. And that is why the wet oxidation would not be a great technique when we want to use it as a gate oxide. So, what we need to do is we need to understand which kind of oxidation technique we need to use, whether dry oxidation technique when it is gate or whether oxygen technique when it is wet oxidation. So, this is what we need to do.

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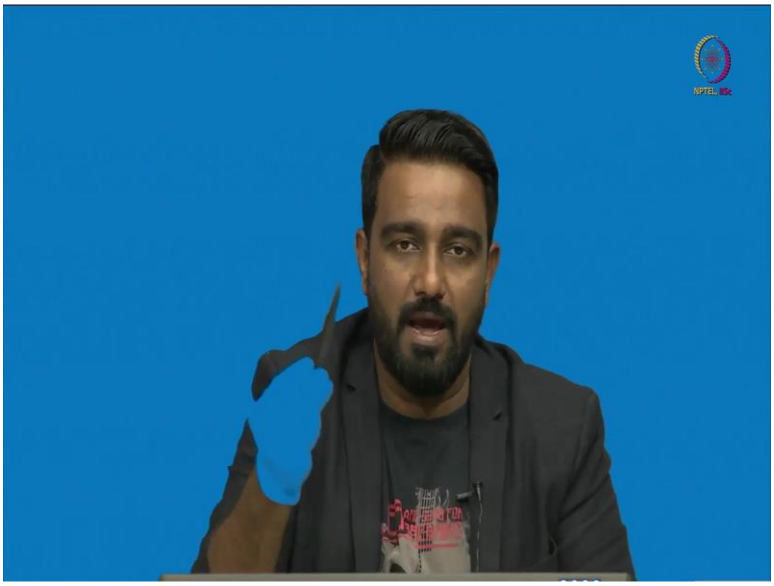

Let me just show you yesterday I was talking about the silicon wafer. And how the silicon wafer looks like what is the roughness of the silicon wafer or how smooth the silicon wafer can be there. This is just I am wearing gloves, so not to contaminate my silicon wafer. But is this is the right attire? No. If you work in a clean room, this is good. My hand disappears, so this is another thing that you need to understand why this thing happens. It is like a magician. But the point is that if you use silicon wafer, then there is something called tweezer. I hope you can see tweezer at least here. You can see the tweezer here that is better because the gloves disappear. So, you can see it very clearly. This is what? It is Tweezer.

How it looks like, so the easier way to understand any subject or any topic within subject is to correlate with our daily activities, how does this looks like? You see like holding something, it looks like something holding. So, so let us correlate in the daily activity, I hope that every one of you has in some time in your life have ate roti. So, to hold the roti, and to twist it like to put it on the second surface, the bottom layer top layer, we hold it, and that is a bigger tweezer. It is not called tweezer, it is called something else let us not go into that, but it is similar mechanism to hold something.

But now, to hold a silicon wafer it is very important that first you should not directly hold it with hand. Why? Because your hand would have sodium and that will cause a contamination on to the silicon wafer. Second is you should use tweezer, there is a way to use tweezer, you should not press too much. You should have enough force to or enough pressure to hold a silicon wafer.

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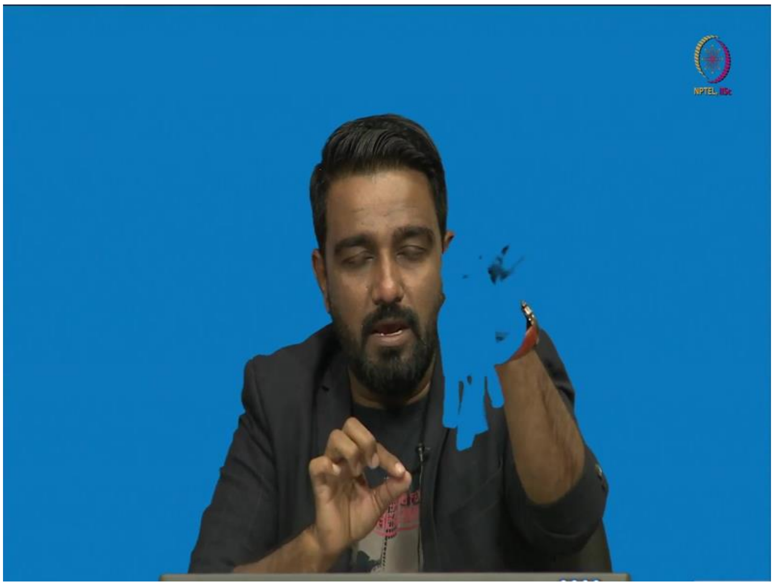

So, when you have silicon wafer, and if I want to hold the silicon wafer, I will hold the silicon wafer in the way I am holding right now, you can see. So, my point is, if I want to hold it, and I will show it to you, let me just hold it and show it to you, you can see this is a silicon wafer. And if I just do this, you can see the reflection, and that means this is a polished side, and there is a flat here. If you really closely see there is a flat. It is not circular, is a flat. I have shown in the last lecture, what is the reason of this flat. There is secondary flat here, if you see there is small flat here, you may not be able to see very clearly but there is a primary flat here, secondary flat here.

Now, let me show you the backside of the silicon wafer, how does it looks like? So, if I hold this silicon wafer from the backside, you can see this is the rough surface. So, this is what we get from the bowl, when you slice it, lap it, polished it, then you get this smooth surface. So, this is backside is rough, you have this surface, and when you actually use the silicon wafer, you get when you polish it, you get this surface, see. So, this is the silicon wafer, and it is very thin, it is very thin. So, you have a thin wafer it looks like a wafer. And this is a 4-inch wafer. So, thickness is about 500 microns, 4-inch silicon wafer, thickness around 500 micrometers.

So, the point of showing you this thing is that when you want to use silicon as a substrate first, you need to clean the wafer, there is a reason of clean the wafer to remove the contaminants. But additionally, there is a single side polished wafer that we know and double side polished wafer. In double side polisedh wafer both the sides would be equally polished. In single side polished wafer, you do not have that. Now, suppose I had touched my sleeves right now, can I hold the wafer again? No. First, if I am using something, I should not touch my clothes. This is something, which is for the lecture, if I would be in a lab, I will wear a cleanroom gown and then you will enter the lab.

So, there is no point of touching the gown. Suppose I have itchiness in my eyes, can I use these gloves? No. In spite of there is no chemical I have touched because I am in the cleanroom, I should not touch anything with my gloves, the right way is you remove the gloves. And the way of removing you see I am holding here, then the second one would be like this. And that is it and you throw it you just throw it and that is end of the story and then you go and wash your hand and then start using the things. Now, here because we have just silicon wafer they were clean gloves as to show it to you.

So, I do not I am not going out but the point is this is how the silicon wafer looks like single side polished, double side polished, 4-inch wafer, primary flat, secondary flat that with respect to primary flat, if secondary flat are placed at different angles and depending on that you can say it is a P type wafer, N type wafer, 1 0 0 or 1 1 1.

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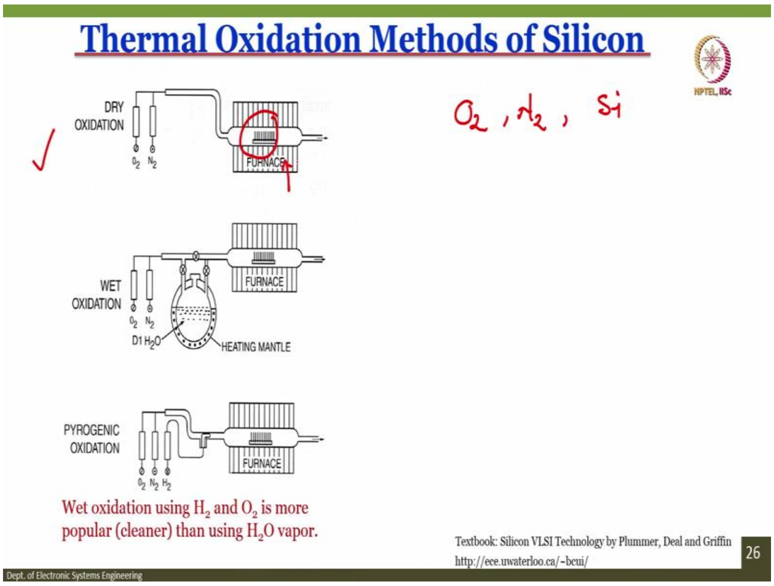

Thermal Oxidation Methods of Silicon

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O_2 , N_2 , Si

Wet oxidation using H_2 and O_2 is more popular (cleaner) than using H_2O vapor.

Textbook: Silicon VLSI Technology by Plummer, Deal and Griffin
http://ece.uwaterloo.ca/~bcui/

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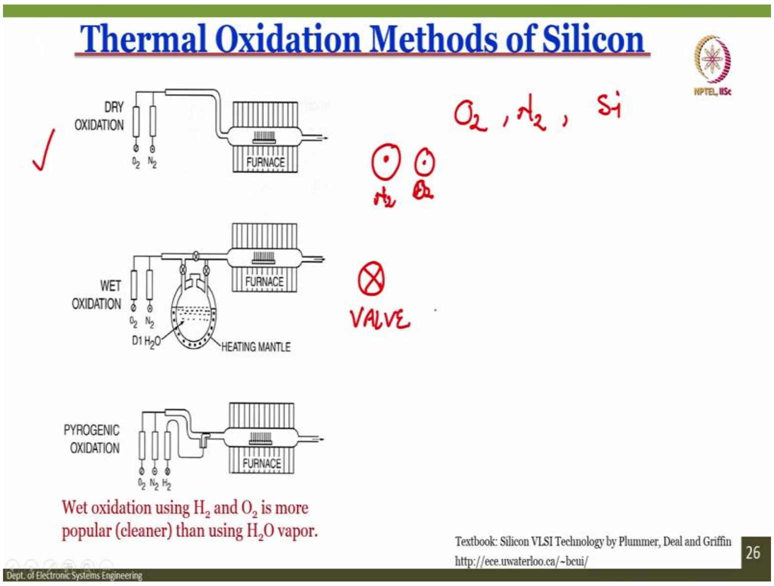

Thermal Oxidation Methods of Silicon

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O_2 , N_2 , Si

N_2 O_2

⊗ VALVE

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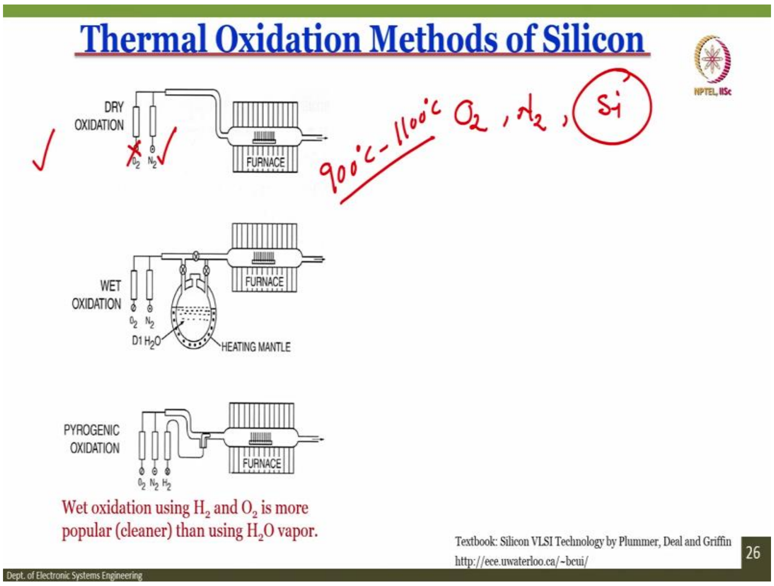

Thermal Oxidation Methods of Silicon

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900°C – 1100°C O_2 , N_2 , Si

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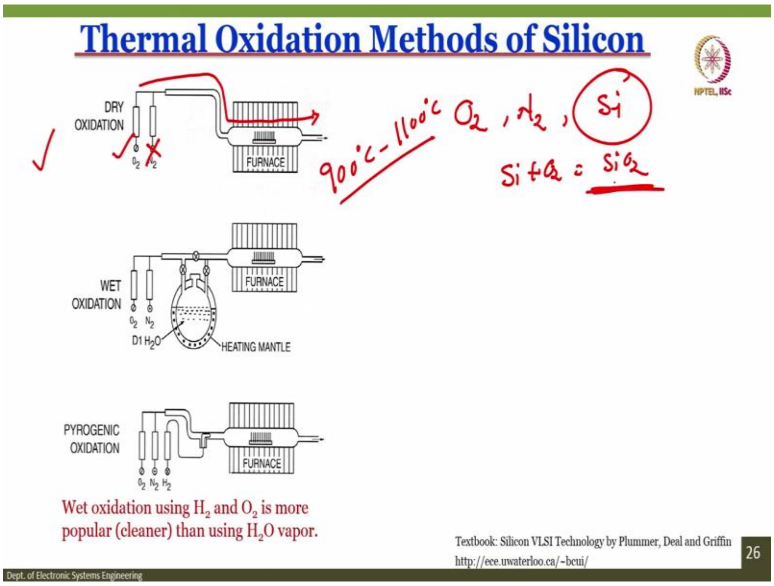

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So, let us go further in this lecture and if you see the slide, we have oxide. Now, this is just a silicon wafer that I have shown to you, but when there is a oxide how it looks like? I will show in the next lecture. So, now, this dry oxidation. So, let us see the first one which is a dry oxidation. In this technique, what you have? You have oxygen and you have nitrogen and you have silicon. Where are silicon wafers? Silicon wafers are here. And silicon wafers are placed in what? Silicon wafers are placed in a furnace. So, you already know the way the reaction occurs would be, first this is a valve, the circle with a dot is a N_2 and circle with a dot is O_2. And then this one here circle with a cross is a valve.

Now, let us understand first the dry oxidation technique which is the first one. Here what happens is initially when these wafers are placed in the furnace only nitrogen is allowed to flow, not oxygen. Oxygen is not allowed only nitrogen flows. In presence of nitrogen these wafers are placed inside the furnace, why? Because nitrogen is an inert gas it will not have any reaction with silicon. So, then we use nitrogen as a carrier gas.

Now, once the wafers are placed in the furnace, you stop nitrogen and the temperature is achieved whatever temperature you want to use or we optimized for silicon dioxide, we have discussed it is between 900 degree centigrade to 1100 degree centigrade. This is the range in which the thermal oxidation is generally performed.

So, you have a wafers, you wafers have in the furnace and you have placed wafers in the presence of nitrogen. Now, you close the nitrogen, and let the oxygen flow through this. So, close the nitrogen open the oxygen let the oxygen flow through the furnace and comes out. When this happens then there is the formation of silicon plus oxygen, gives SiO_2.

There is a formation of silicon dioxide. So, this is how the reaction happens the chemistry happens and the formation of the silicon dioxide on silicon wafer. But if you want to go to the next technique thermal oxidation technique, then it is a wet oxidation technique.

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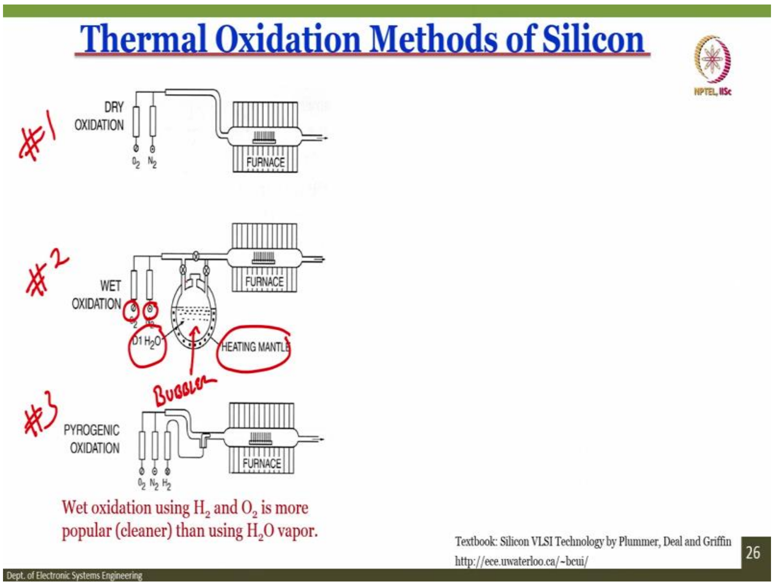

Thermal Oxidation Methods of Silicon

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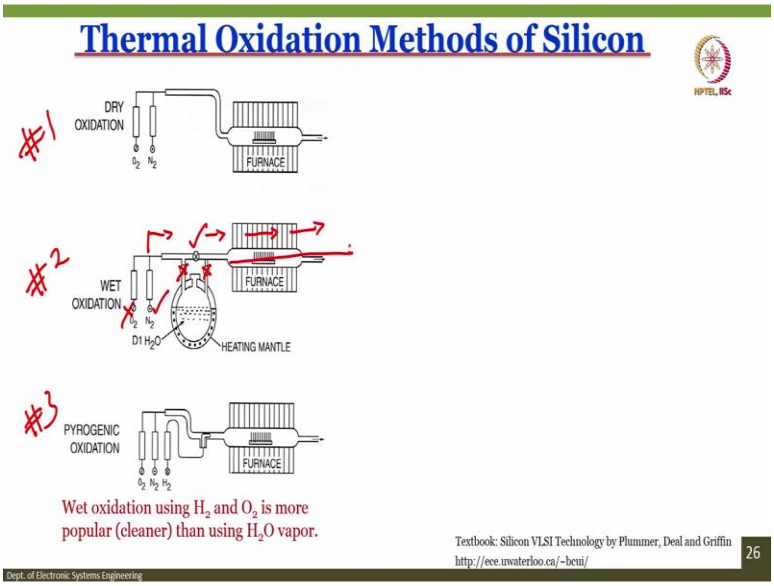

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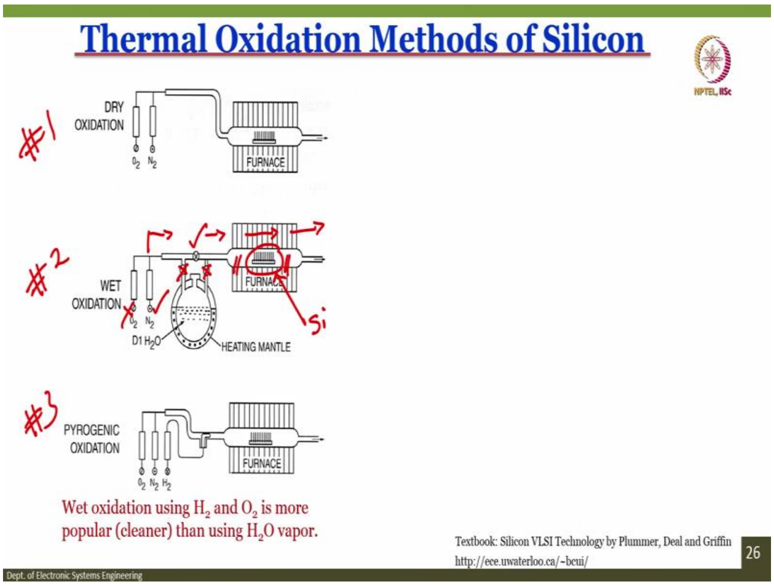

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Let us see second technique of wet oxidation technique. Let us see 1, 2, 3 that is easy. So, number 1, number 2, number 3. Now, wet oxidation technique, we have nitrogen, we have oxygen. We have H_20_2. There is a heating mantle and that means this will form a bubbler. So, when you heat the water, what will happen? Water will convert to water vapour. Water vapour is there. And now, initially what you do? Initially when you want to place the wafers inside the furnace, you allow nitrogen close oxygen, close this valve, close this valve, open this valve.

That means, nitrogen will flow through this in the furnace and will come out. Furnace is like of course, through here just showing for easy representation. Now, where are the silicon wafers? Silicon wafers are placed inside the furnace. And in the presence of nitrogen the silicon will not form any silicon dioxide the reason of nitrogen also is to purge is to remove the excess oxygen which may be there in the furnace because there is air, air contains oxygen. So, just purging the air out of the furnace is also the role of the nitrogen.

Now, once you place the silicon wafers in the presence of nitrogen gas in the furnace and you have achieved the temperature which you want for thermal oxidation, then what you do the next step.

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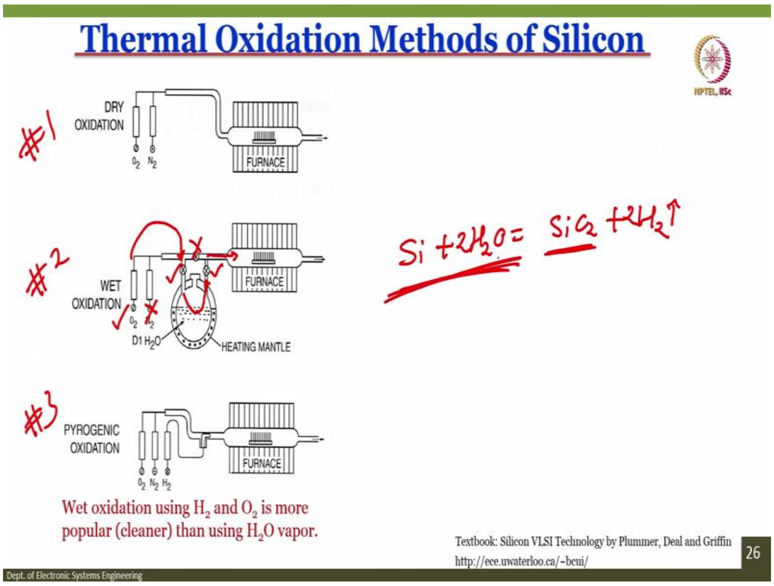

Thermal Oxidation Methods of Silicon

$Si + 2H_2O = SiO_2 + 2H_2\uparrow$

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The next step is that you close the nitrogen open the oxygen, close this valve, open this valve and open this valve. Now, what will happen? The oxygen will flow through here, through here, back to here and into the chamber. So, when oxygen flows in this path then the water vapour which is there in the bubbler, it will carry the water vapour inside the furnace and then this is a silicon wafer and silicon wafer plus H_2O gives SiO_2 plus H_2. Balance the equation O_2. So, 2H, here 2H, $2H_2O$, the equation is balanced that this will be the byproduct so, hydrogen will come out and silicon dioxide is formed using the wet oxidation technique. This is a wet oxidation technique.

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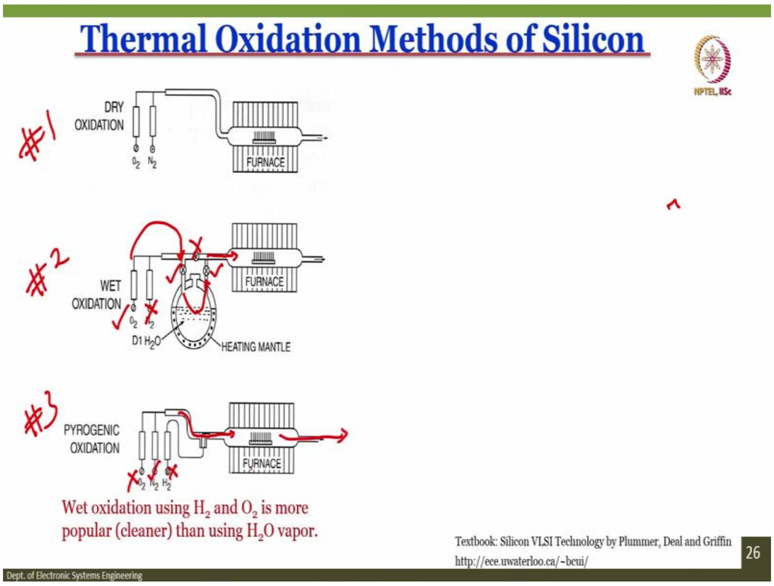

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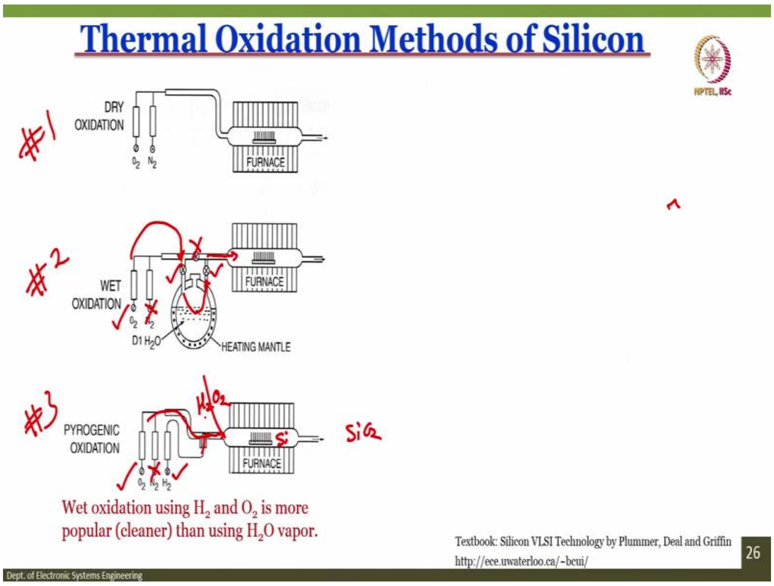

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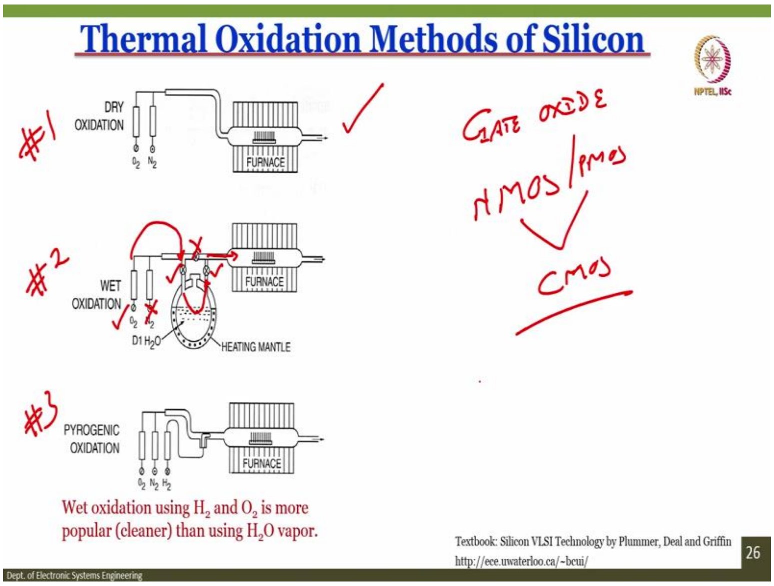

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The last one, how it works? There is a pyrogenic oxidation, pyrogenic oxidation does not require you to have a bubbler and water vapour. But instead of that what happens is initially only nitrogen is open, hydrogen is closed, oxygen is closed, nitrogen will flow through this all the way here into the furnace and the wafers are placed in the furnace in presence of nitrogen.

Now, what will happen. That we will open H_2, will open, O_2 will close N_2. Then this O_2 will mix with H_2 here and this forms the H_2O or H_2O_2. Because H_2 and O_2 this both forms the water vapour H_2O, we will then balance equation later and then the silicon is there. So, that is form silicon dioxide again.

This is way cleaner and more popular rather than using the water vapour which is H_2O. This way you can grow silicon dioxide faster also. But the best quality amongst all these 3 thermal oxidation technique is the dry oxidation. That is why when you use gate oxide, the people who do not know what is gate oxide, we are talking about the metal oxide semiconductor, whether it is NMOS or whether this PMOS or any combination of NMOS and PMOS, which is CMOS. We have the transistors that are formed where there is a source there is a drain and there is a gate and for the gate there should be a thin layer of oxide and that thin layer of oxide should have extremely good quality and that good quality can be obtained with help of the dry oxidation. So, this is the way to grow the silicon dioxide.

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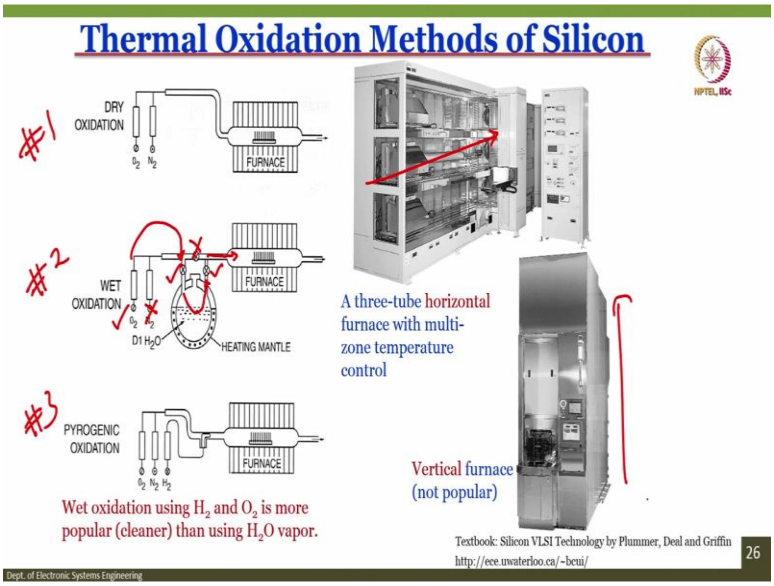

Thermal Oxidation Methods of Silicon

A three-tube horizontal furnace with multi-zone temperature control

Vertical furnace (not popular)

Wet oxidation using H_2 and O_2 is more popular (cleaner) than using H_2O vapor.

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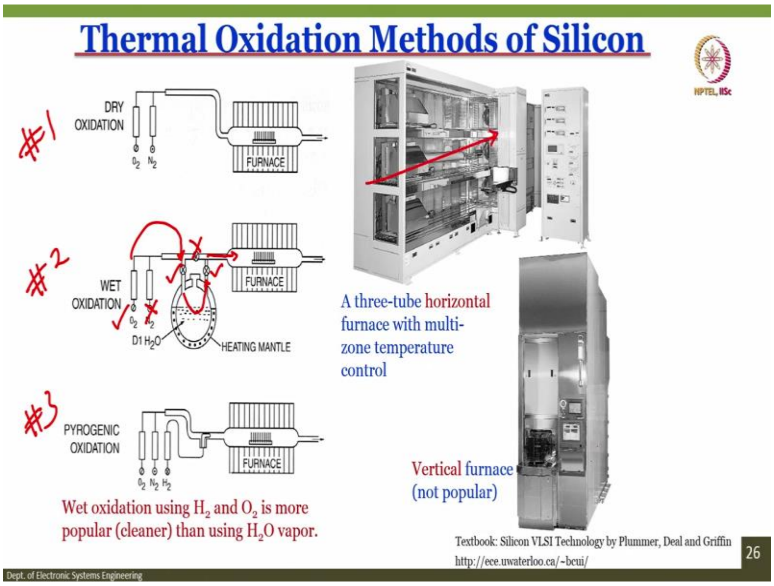

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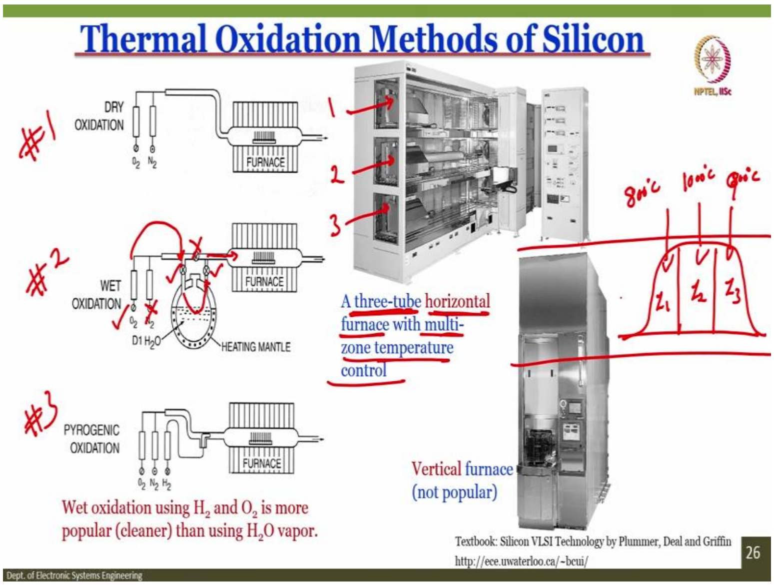

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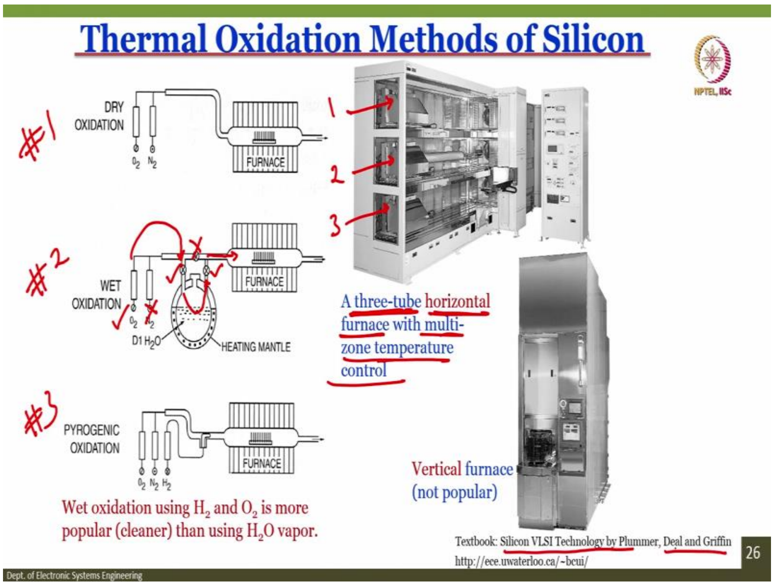

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Now, you will see here the photo of the chamber. So, there are 2 furnaces. These are called horizontal tube furnace and vertical tube furnace then it is very easy. The furnace are placed horizontally, furnace are placed vertically. The vertical furnace are not that popular compared to horizontal furnace. Also, we can have 3 different furnaces, furnace 1, 2, 3. So, what we call is a three-tube horizontal furnace with multi zone temperature control. What is multi zone temperature control? That means that you have this, you have zone 1, zone 2, zone 3 across the tube. So, if I draw the tube somewhere in the center you would have this zone 1, zone 2, zone 3.

So, you can have different temperature of each zone that means, you have multi zone temperature control. One zone can be let us say at 800 degree centigrade, second can be 1000 degree centigrade, third can be again at 800 degree centigrade or 900 degree centigrade depending on how you want to optimize the parameter.

So, that is the advantage of having the 3-tube horizontal furnace with multi zone temperature control. If you want to read as I have given the references, you can read the Silicon VLSI Technology by Plummer, Deal and Griffin. And it has a lot of information about the thermal oxidation and the way thermal oxidation is performed.

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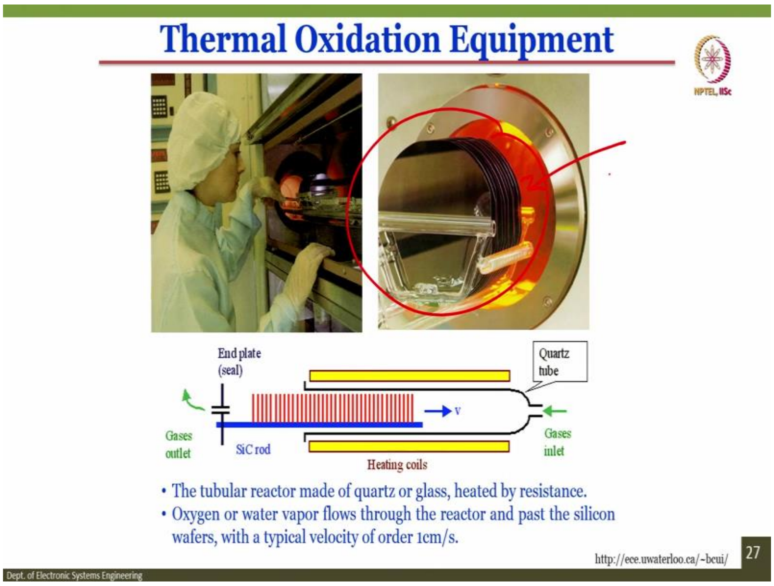

Thermal Oxidation Equipment

- The tubular reactor made of quartz or glass, heated by resistance.
- Oxygen or water vapor flows through the reactor and past the silicon wafers, with a typical velocity of order 1cm/s.

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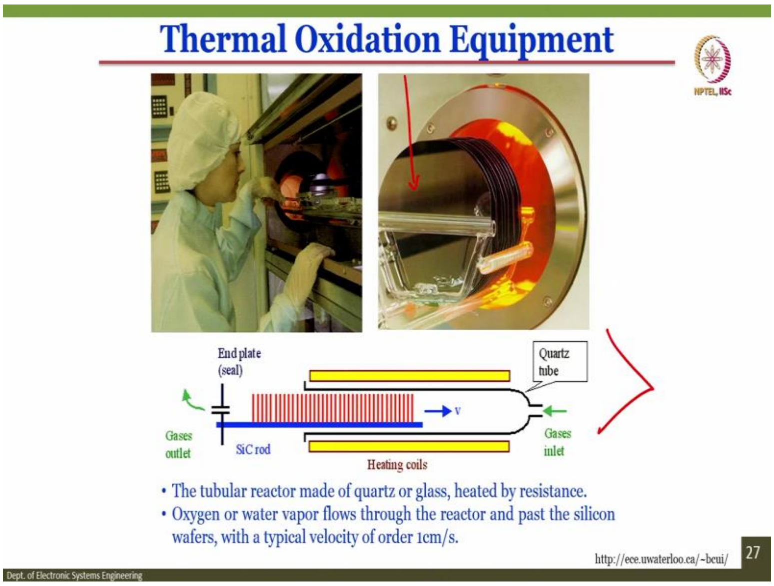

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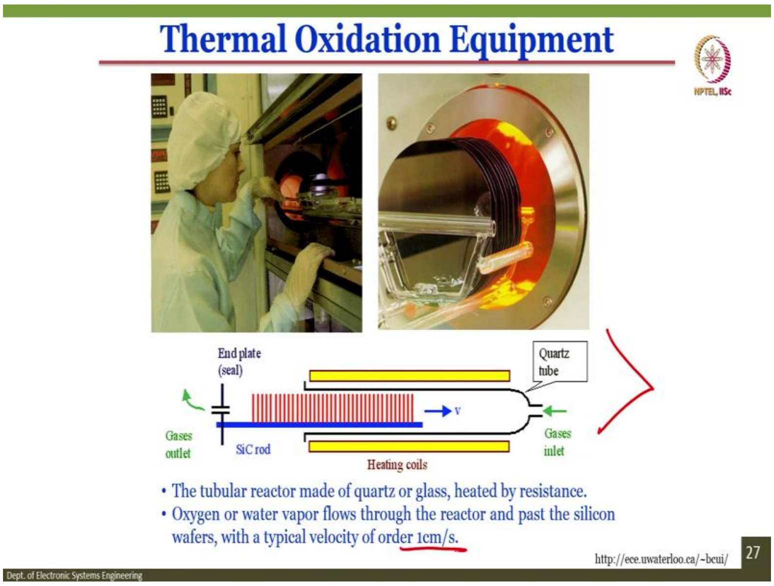

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Now, this schematic sorry, this photograph shows a engineer working in a cleanroom and if you see she is placing the horizontal tube furnace, she is placing the wafers into the horizontal tube furnace and this is another photograph of the same, you can see the temperature it is very high temperature and you have to push this inside the furnace. So, you can use a silicon rod, silicon carbide rod. Silicon carbide can withstand very high temperature. So, you can push these wafers into the furnace in the presence of nitrogen and then you close the nitrogen and start oxygen or H_2 plus O_2 or H_2O vapours, we have seen that.

So, this is this representation of the same, silicon wafer you have already seen how it looks like and I have shown it to you one single wafer. And we have discussed in the previous lectures that there is always a batch fabrication. Not like one wafer after second wafer after third wafer that it always goes in a batch. So, batch of 25 or 25 first goes for thermal oxidation.

Now, the tubular reactor made up of quartz or glass heated by resistance and oxygen or water vapour flows to the reactor and past the silicon with a typical velocity of 1 centimeter per second. So, it is a super easy technique to understand once you understand the concept. And if you want to see the steps.

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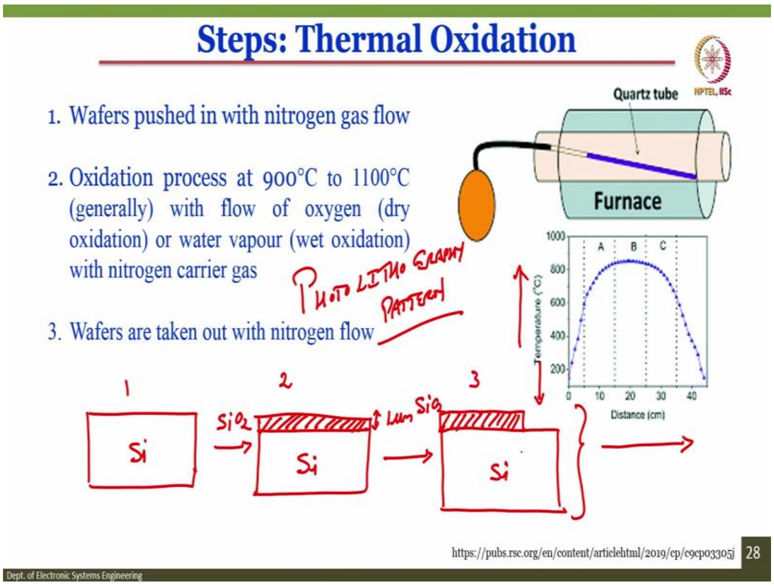

Steps: Thermal Oxidation

1. Wafers pushed in with nitrogen gas flow
2. Oxidation process at 900°C to 1100°C (generally) with flow of oxygen (dry oxidation) or water vapour (wet oxidation) with nitrogen carrier gas
3. Wafers are taken out with nitrogen flow

https://pubs.rsc.org/en/content/articlehtml/2019/cp/c9cp03305j

So, these are the same step, you can see the temperature versus the distance. This is a furnace quartz tube because quartz again can withstand very high temperature and wafers are pushed with nitrogen gas flow which we already know. Oxidation process is between 900 degree centigrade and 1100 degree centigrade with the flow of oxygen either is dry oxidation or water vapour which is wet oxidation and wafers are taken out with the nitrogen flow. So, again when you finished the oxidation cycle, you need to start the nitrogen again let the furnace cool down and you can then push out or take out the wafers from the furnace in the presence of nitrogen flow.

Now, the question is, once you grow the silicon dioxide, you want to understand what is the thickness of silicon dioxide, what does it mean? Suppose I have a silicon wafer and I grow silicon dioxide on silicon wafer. Now, I need to know if I say if I claim that this silicon dioxide is 1 micrometer. How would I do that? How would I know? So, for that you need to create a step and I will teach you something called Photo lithography, which will help to pattern the material of your choice. Now, we want to create a step that means using photolithography, I will edge silicon dioxide from this region, you can see here.

So, I will use the photolithography to form silicon dioxide and pattern silicon dioxide in the way I have drawn in this schematic. Now, once I have this wafer, which is this one at step 3, if you say this is step 1, step 2 and step 3.

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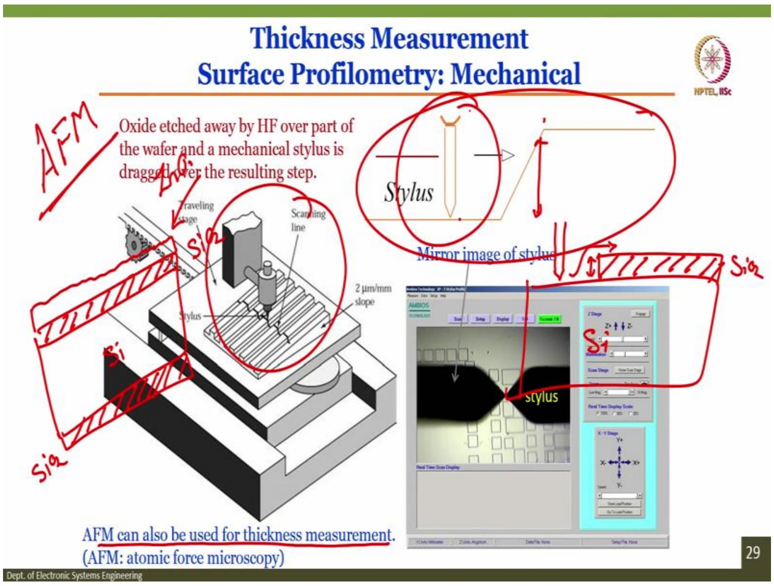
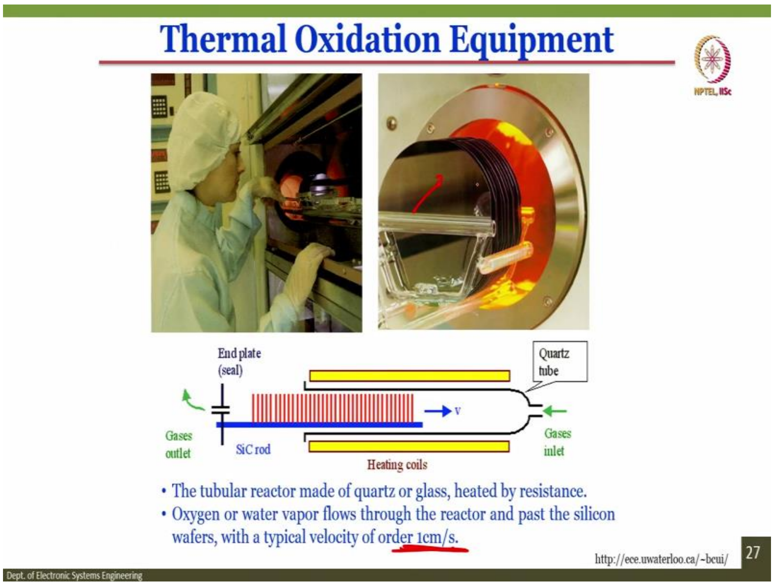


Thickness Measurement
Surface Profilometry: Mechanical

Oxide etched away by HF over part of the wafer and a mechanical stylus is dragged over the resulting step.

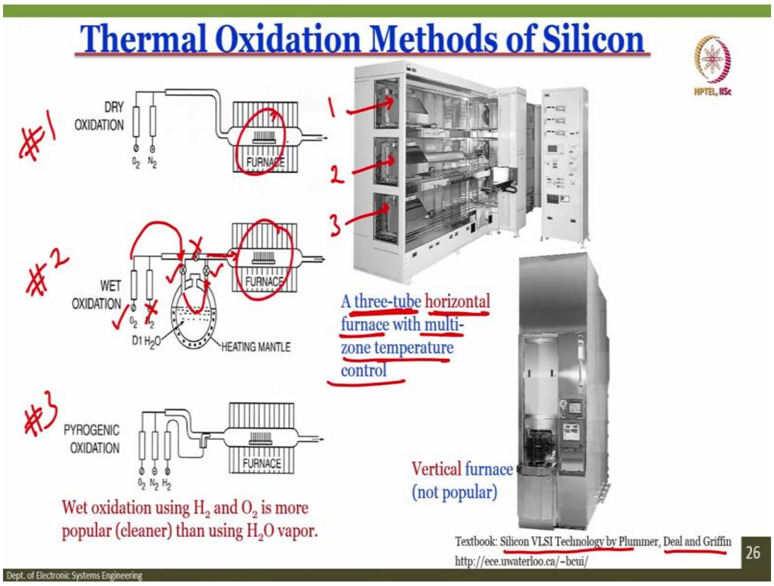
AFM can also be used for thickness measurement.
(AFM: atomic force microscopy)



Thermal Oxidation Equipment

- The tubular reactor made of quartz or glass, heated by resistance.
- Oxygen or water vapor flows through the reactor and past the silicon wafers, with a typical velocity of order 1cm/s.

http://ece.uwaterloo.ca/~bcui/



Thermal Oxidation Methods of Silicon

Wet oxidation using H_2 and O_2 is more popular (cleaner) than using H_2O vapor.

A three-tube horizontal furnace with multi-zone temperature control

Vertical furnace (not popular)

Textbook: Silicon VLSI Technology by Plummer, Deal and Griffin
http://ece.uwaterloo.ca/~bcui/

Dept. of Electronic Systems Engineering

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The wafer at the step 3 I will take it and I will use something called Alpha step profilometer or profilometer. This is used to understand the thickness of silicon dioxide. So, now, if you have this wafer this is the same example, because, what we have drawn is like this initially, instead of that if I draw like this, this is silicon, this is silicon dioxide and the stylus is the diamond tip. It moves from this region and it goes like this, which is shown here also you see this one. So, when it goes from this to this there is a height, here there is a height. So, that height we can record it with the help of the Alpha step profilometer.

And, this can also be used, the same technique can also be used to measure the roughness of the silicon wafer or the roughness material on the silicon wafer both, either or because silicon wafer can be single side polished, silicon wafer can be double side polished, if it is a single side polish, what is the roughness, if it is the double side polish, what is the roughness. If you grow the material like gold, you deposit material like gold or you deposit material like zinc oxide or tin oxide or indium tin oxide or indium oxide. What is the material? What is the roughness of the material on the silicon wafer or on the oxidized silicon wafer?

To learn that we can use alpha step profilometer or surface profilometry. It is a mechanical way of measuring the thickness of the or height of the oxide layer or any other layer per se. Because here we have taken example of silicon dioxide because we are talking about thermal oxidation, but in case if you do not want to use silicon dioxide and if you want to use some material, it can be any material, it can be semiconductor, it can be metal, which is deposited or oxidized silicon substrate.

And then let us say what I mean is if you have a silicon wafer and you have an oxide layer and generally when you grow oxide, the oxide will grow on both the sides. So, why is grows on both the sides? You can see this surface and the back surface both are in contact with oxygen. That is why both the sides will be, in this case also you can see both the sides of the wafer will be exposed to the oxygen and that is why when we always draw then draws in both the sides silicon dioxide on the bottom.

Silicon dioxide on the top of the wafer is a silicon and what I mean is if you deposit let us say zinc oxide or any semiconducting oxide or metal and I am just saying example of zinc oxide, zinc oxide ZnO. Then what is the roughness, what is this roughness? Here that you will see like this wavy lines. What is the roughness of this? Everyone want to measure the roughness then there is a technique called atomic force microscopy, AFM and that is what is written here. AFM also can be used for thickness measurement. In AFM instead of using the diamond tip which is here we use silicon cantilever.

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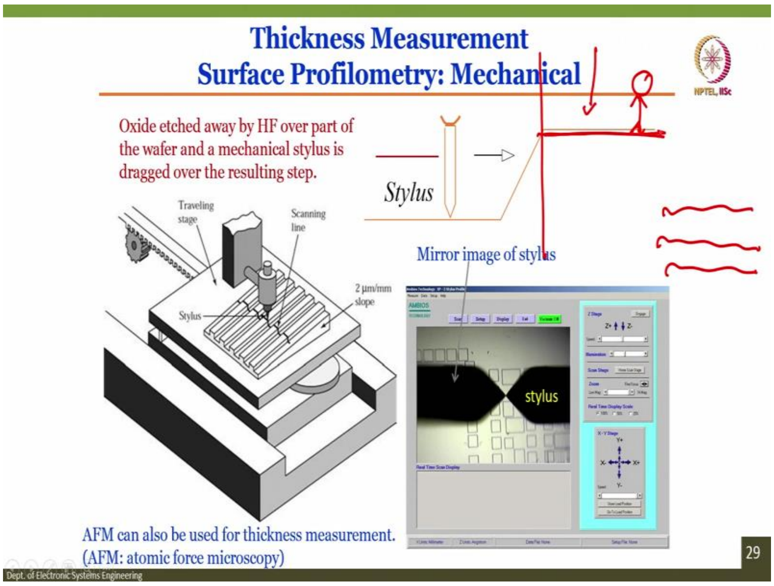

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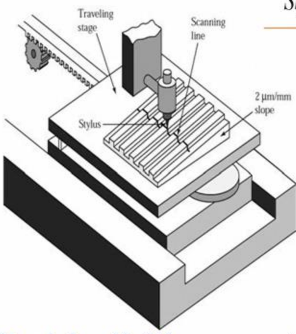

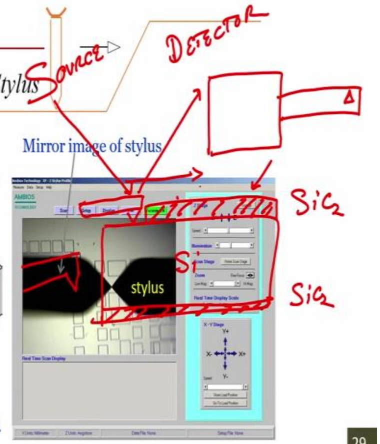

AFM can also be used for thickness measurement. (AFM: atomic force microscopy)

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Surface Profilometry: Mechanical

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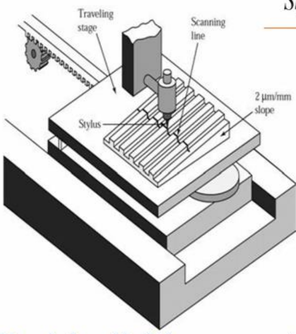

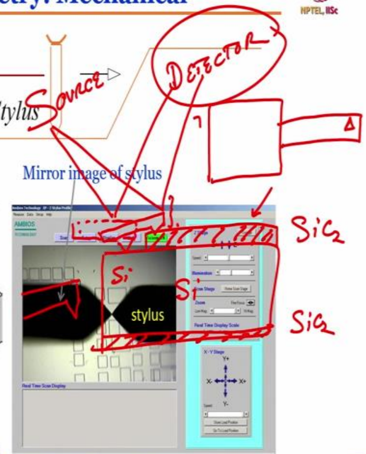

AFM can also be used for thickness measurement. (AFM: atomic force microscopy)

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Surface Profilometry: Mechanical

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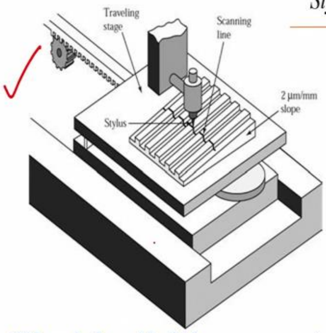

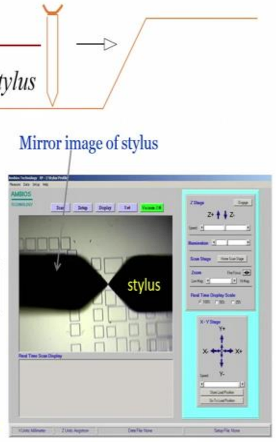

AFM can also be used for thickness measurement. (AFM: atomic force microscopy)

Now, what is cantilever? Let me give an example. And everyone again what I said is you should correlate your subject, your topics that you learn in your college or in school with the daily activities. And then it will be so easy for you to remember cantilever. Have you seen cantilever in your life? You have seen. So, suppose assume that this is a diving boat and there is a person here diving into the water. What is this thing, this this plank, this becomes cantilever, is not it?

So, in silicon wafer, if you want to fabricate a cantilever then you can form cantilever like this with a tip with a diamond with a tip like this. Now, this tip. So, if I have silicon dioxide silicon dioxide, silicon dioxide and then I have a cantilever that moves in this direction. There is a light that falls on the cantilever like this and there is a reflection that goes to the photo detector or a detector. So, for easy thing we say source and detector. So, light falls on the cantilever.

Now, when the cantilever will come here in this area silicon dioxide area, what will happen? It will start bending. It will start like this, the angle will change, is not it? Now, this change in angle that means, if I bring the cantilever into this silicon dioxide region what, will happen? The silicon cantilever will form something like this. So, now, initially it was in this position. So, the source light falling will go to detector.

Now, the source light has an angle will by which it has to fall because there is a change in the angle of the cantilever because of the thickness of the silicon dioxide there because of the step. So, now, the detector the light that falls to the detector after falling through the cantilever will be different compared to the original cantilever when it was on this silicon. When it was a thin silicon versus when it is on silicon dioxide you have a different way the light reflects from the cantilever.

So, through this mechanism, we can also understand what is the thickness of the silicon dioxide or to understand the roughness of the material that is deposited on to the oxidized silicon wafer. So, silicon dioxide when it is grown on silicon wafer, the silicon wafer is then also called oxidized silicon wafer.

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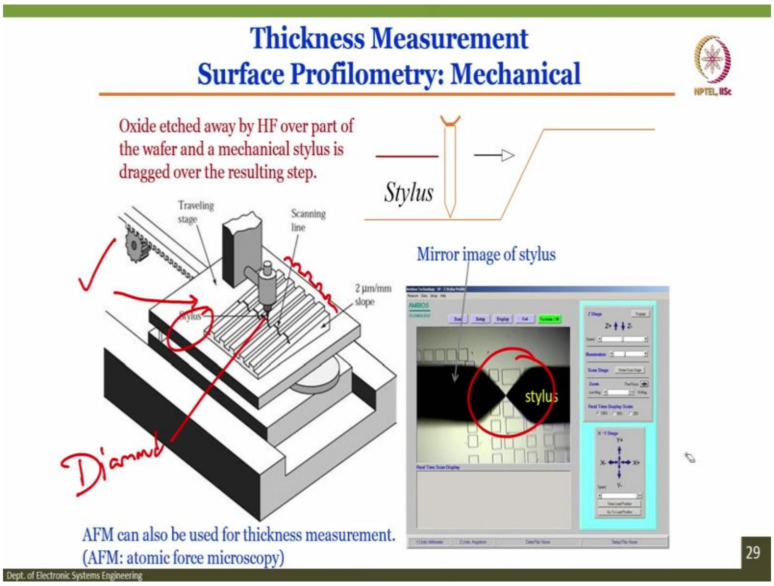

Thickness Measurement
Surface Profilometry: Mechanical

Oxide etched away by HF over part of the wafer and a mechanical stylus is dragged over the resulting step.

AFM can also be used for thickness measurement.
(AFM: atomic force microscopy)

In this case, which is a mechanical way now mechanical way the disadvantage of this limitation of this is that we need to create a step. When you create a step that means that you are destroying that particular material, what does it mean?

That you have silicon, you have silicon dioxide you are patterning silicon dioxide means you are etching silicon dioxide from the remaining area. So, create a step but then that that wafer or that device or that that portion of the wafer will not be utilized anymore. So, it is a mechanical way of measuring the roughness or the height of the silicon dioxide also has a limitation that it is a damaging way of measuring the thickness or roughness of the material.

But if you see the mechanism there is a travelling stage this is a travelling stage which is here then there is a stylus generally stylus is a diamond tip diamond and then there is a scanning line and then there are steps. So, what happens is it will just form like this and this change, this change is recorded and you can see here in this case and you can measure what is the, we can also control the speed of Z axis, slow, fast, elimination, scan stage, zooming. What we want to see in real time display scale, you want to see 100 percent or zooming image, you have XY stage you can manipulate the manure the XY stage and you can also go for the you can control the load position as well.

So, this is how the there is a UI that comes with the profilometer through which you can measure the surface roughness or thickness of the material, roughness or thickness there is a difference, where how thick the material is and how rough the material is, it can be 2 micron thick, but what is the roughness? It is 100 nanometers, 200 and nanometer, 0.1-micron, 0.2

micron if you want to know the roughness, you can measure, if you know the thickness you measure for roughness measurement mostly the atomic force microscopy is used where I told about the cantilever mechanism.

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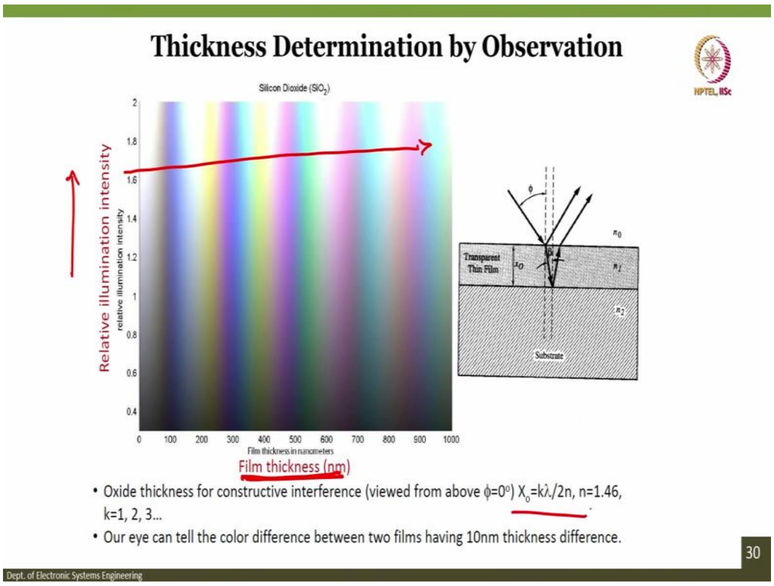

Thickness Determination by Observation

- Oxide thickness for constructive interference (viewed from above $\phi=0^\circ$) $X_0=k\lambda/2n$, n=1.46, k=1, 2, 3...
- Our eye can tell the color difference between two films having 10nm thickness difference.

So, now, if you see the screen again in this case what you observe is that you see the colour, colour of silicon dioxide and with relative illumination intensity. So, you have relative illumination density versus the thickness of the film. As the film gets thicker it changes the colour. You can see the colour change and that is the oxide thickness for constructive interference, you know the constructive interference versus destructive interference can be given by this equation where you have n equals to 1.46 and k can be from 1, 2, 3 and so on.

So, I can tell you the colour difference between 2 films having 10 nanometer thickness that is the limitation of our eye that it can tell you with 10 nanometer thickness again if you are working from many years into in a fab where you can see and you are working on silicon dioxide exclusively that how the thickness of silicon dioxide changes with respect to the or how the intensity relative illumination intensity changes with respect to the thickness of the film.

So, from 0 to 1000 that means from 0 to 1 micrometer, 1000 nanometer is 1 micrometer you can see the change in the way the silicon dioxide will look like. I will show it to you in one of the lectures how silicon dioxide looks like and compare it with silicon, so, that you understand that when there is a silicon dioxide how the wafer looks like.

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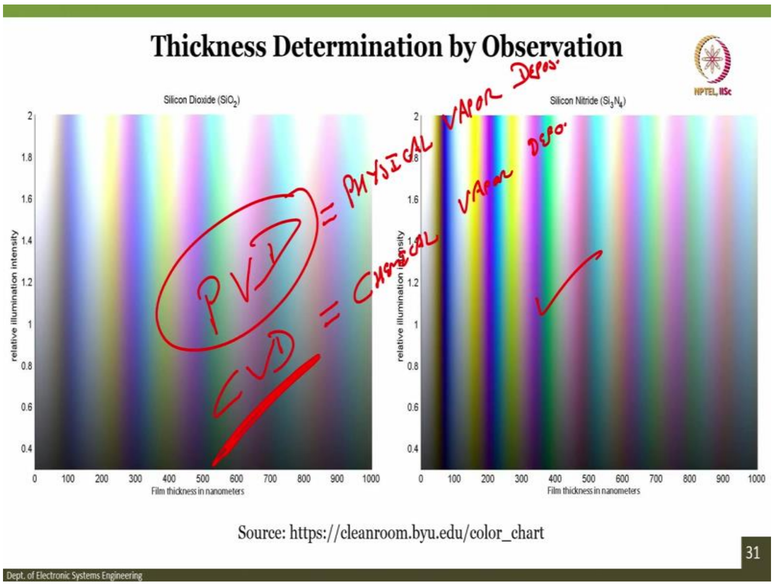

Thickness Determination by Observation

PVD = PHYSICAL VAPOR DEPOS.

CVD = CHEMICAL VAPOR DEPO.

Source: https://cleanroom.byu.edu/color_chart

Now, you will say that why only silicon dioxide, why not the insulating material or what about silicon nitride? So, the answer is yes, you can also deposit silicon nitride or grow silicon nitride with the CVD technique. We have not learn about CVD right now. But there are 2 techniques, one is PVD, another is CVD. PVD stands for physical vapour both special are okay vapour, vapour, both are okay deposition. And CVD will be chemical vapour deposition. So, in CVD using CVD technique, you can grow silicon nitride, you can sputter silicon nitride as well with PVD but the rate of sputtering is extremely low, you can also sputter silicon dioxide again using sputtering technique.

So, there are advantages and disadvantages of physical vapour deposition and chemical vapour deposition. We will into detail in one of the lectures. So, again when it comes to silicon nitride also you can kind of understand from the colour from the intensity you can understand what should be the thickness of the silicon dioxide.

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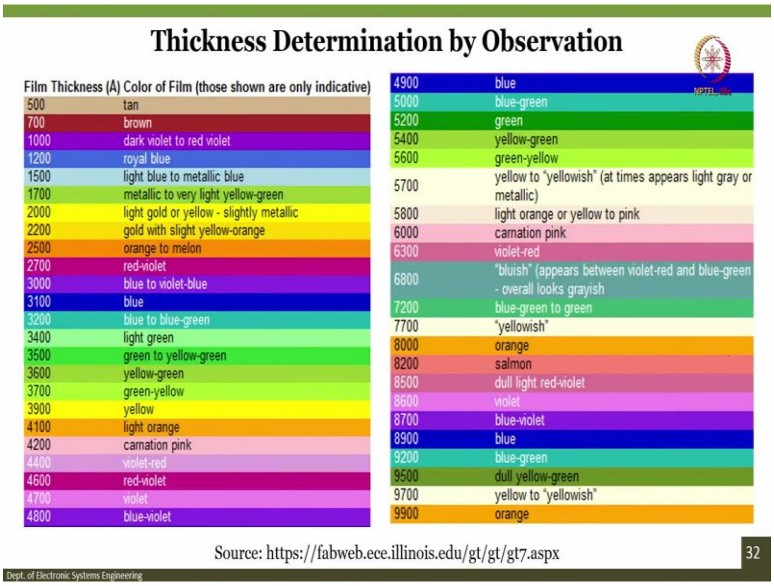

Thickness Determination by Observation

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

Source: https://fabweb.ece.illinois.edu/gt/gt/gt7.aspx

So, in reality it is this complicated. So, you see that right from 10 all the way to blue violet how the thickness changes and how the colored bands are there. Same thing goes for blue all the way to 9900 thing which is orange. So, generally when you see the silicon oxide or oxidized silicon wafer, you will see either one of these particular light.

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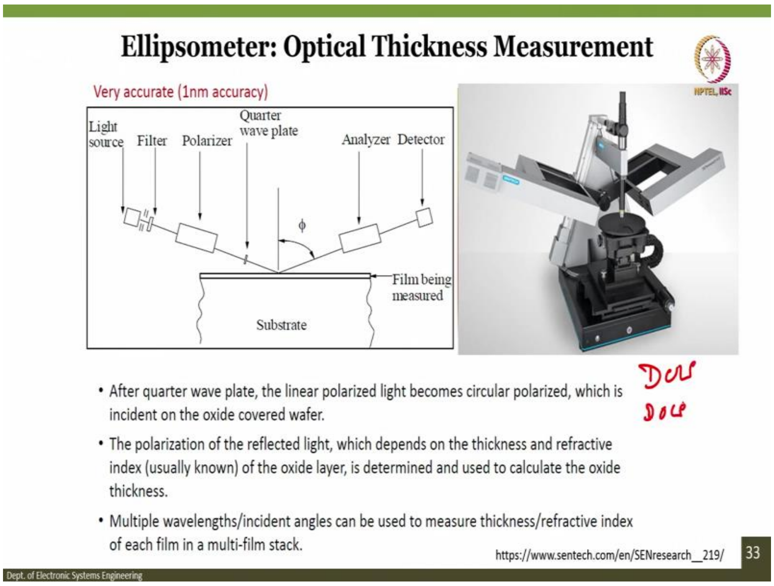


Ellipsometer: Optical Thickness Measurement

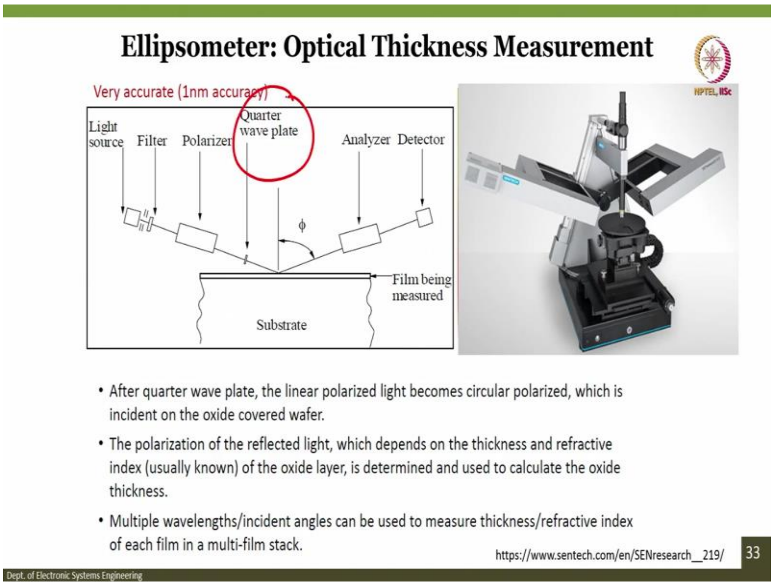
Very accurate (1nm accuracy)

Dcs

Docp

- After quarter wave plate, the linear polarized light becomes circular polarized, which is incident on the oxide covered wafer.
- The polarization of the reflected light, which depends on the thickness and refractive index (usually known) of the oxide layer, is determined and used to calculate the oxide thickness.
- Multiple wavelengths/incident angles can be used to measure thickness/refractive index of each film in a multi-film stack.

https://www.sentech.com/en/SENresearch__219/



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https://www.sentech.com/en/SENresearch__219/

Now, what about different technique in which you do not have to really sacrifice the wafer or sacrifice the device that means that you do not have to pattern the silicon dioxide to measure what is the thickness? For that you have something called ellipsometer, and ellipsometer or ellipsometer it is optical thickness measurement technique is an extremely accurate 1 nanometer accuracy. And in this there is a light source filter polarizer there is a quarter wave plate if the light falls on the film that is being measured and then it passes through the analyzer and finally to the detector.

Now, after the quarter wave plate the linear polarized that become circularly polarized. In fact, we will look at the degree of linear polarization and degree of circular polarization, DOLP and DOCP, we will see in one of the classes of how we can use the light as a source or when you use the circular polarizer versus a linear polarizer how the effect of the light on the tissue would be to delineate the tissue types, we will see in one of the lectures.

So, coming back to the slide. The linear polarized light becomes circularly polarized which is incident on the oxide cover wafer. The polarizer of the reflected light which depends on the thickness of the refractive index of the oxide layer and is determined to calculate the oxide thickness.

Finally, multiple wavelengths can be used to measure the thickness refractive index of each film in a multi film stack. Sometimes there is a difficulty, there is a limitation of ellipsometer, this is your homework. I am not going to tell in this class. So, I want you to read about 2 different things. One is what is quarter wave plate, how the quarter wave plate can be used to convert the linear polarized light to circular polarized and second is what is the limitation of ellipsometer and where it cannot be used?

The beauty is that you do not have to distract the wafer there is not a distinctive technique. But there is some limitations. So, find out the limitation of this particular tool. So, with this we will stop talking about the oxidized silicon wafer or the thermal oxidation technique and how we can measure the thickness of silicon dioxide using surface profilometer or using ellipsometer versus destructive technique versus nondestructive technique, how the colours would change depending on the thickness of silicon dioxide, what is wet oxidation, what is the dry oxidation, what are the horizontal tube furnace, what is vertical tube furnace, how the wafers are placed inside, what kind of atmosphere should be there, whether it should be nitrogen or oxygen or oxygen and hydrogen?

So, all things we have seen and now we know that there is a substrate which is silicon and then we have an insulator which is the silicon dioxide. Till now, we have just seen the first step which is your silicon wafer and silicon wafer with silicon dioxide that means oxidized silicon wafer.

In the next step we will see how to deposit layers on to this oxidized silicon wafer. Now, why we need to understand all these things? Because for understanding the advanced neural science part, you need to first understand that for certain disease, for recording the signal, what kind of device we need, and for understanding what kind of device we need, we need to understand the micro fabrication and for understanding micro fabrication, we need to understand different technologies.

So, this is the start of the micro fabrication thing and we will go into depth till the point that we are able to understand how we can fabricate several devices that can be used to for neural science project. So, with that, I will stop here. I will see you in the next class. Till then, you take care. Cheers.