

**Advanced Neural Science for Engineers**  
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**Indian Institute of Science Bangalore**

**Lecture 09**  
**Thermal Oxidation of Silicon and Thickness measurement**

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 a Czochralski technique which we call CZ technique or it is a float zone technique which is called FZ technique. So, Z or Z is same thing, 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 and or a boule actually and from the boule we were slicing the boule from the wafer. So, but the point is the FZ technique because the float zone there is a melting zone between the seed and the feed crystal, the impurity is less. The impurity which is an 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, is a chip, is a sensor there are multiple terms, if a chip I said then chip can integrate or chip can consist of multiple devices.

We have seen one chip which has a electrical sensor which has interdigitated electrode electrodes or micro heater and surrounding the device thermistors or temperature sensors, but if you just say of pressure sensor or a force sensor, it is one sensor. So, a bio chip or a chip, now bio chip when we use a 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, capture the bacteria from the sample, then the sensor that is used for such application, we can call them biosensors and 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 is micro machining.

In micro machining there are two 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. 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 two 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 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 oxygen technique or within the 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 the oxidation is by using oxygen as a carrier gas, not as a carrier gas, oxygen as a reactant gas and hydrogen as a carrier gas. So, we will see that how it works, but the point of the chemistry is that you have oxygen plus

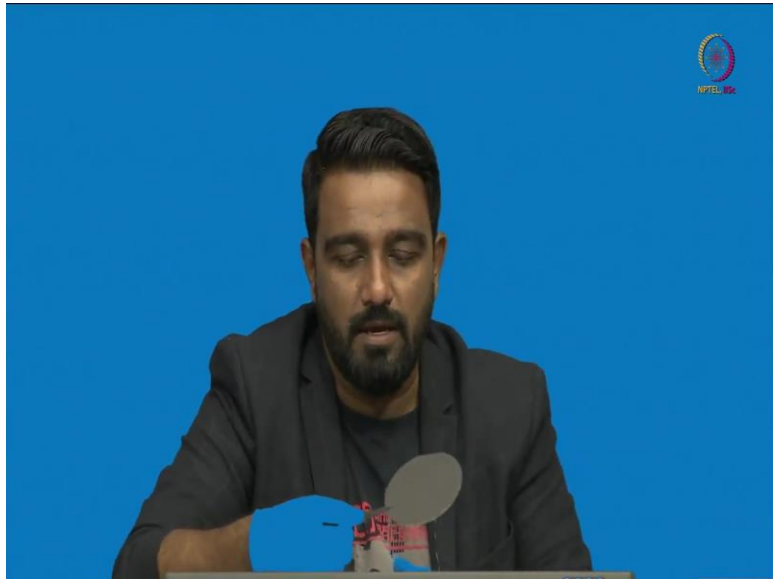
you have silicon. So, silicon plus  $O_2$  gives  $SiO_2$  as simple as that, but the thickness the limitation of this is the thickness of the silicon dioxide.

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 vapor phase. It is a vapor, water vapor, gives  $SiO_2$  plus  $H_2$ , but you have to balance the equation, is not it? So, as silicon plus  $2H_2O$  gives  $SiO_2$  plus  $2H_2$ . Now, what is the hydrogen comes out as a byproduct of it.

So, when hydrogen will come out, there will be the path for 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, correct. So, what we need to do is we need to understand which kind of oxygen technique we need to use whether dry oxidation technique when it is gate or whether wet oxygen technique when it is wet oxidation. So, this is what we need to do.

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Let me assure you yesterday I was talking about the silicon wafer, thank you. And how the silicon wafer looks like what is the roughness of the silicon wafer? Or how smooth silicon wafer can be there? This is just I am wearing gloves, so not to contaminate my silicon wafer. But if this is the attire, no, you have to, 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 tweezers. I hope you can see the tweezers. You can see that tweezers here that is better because the glows disappear. So, you can see it very clearly. This is what? It is tweezers. How it looks like? So, the easier way to understand any subject or any topic within subject is to correlate with our daily activities.

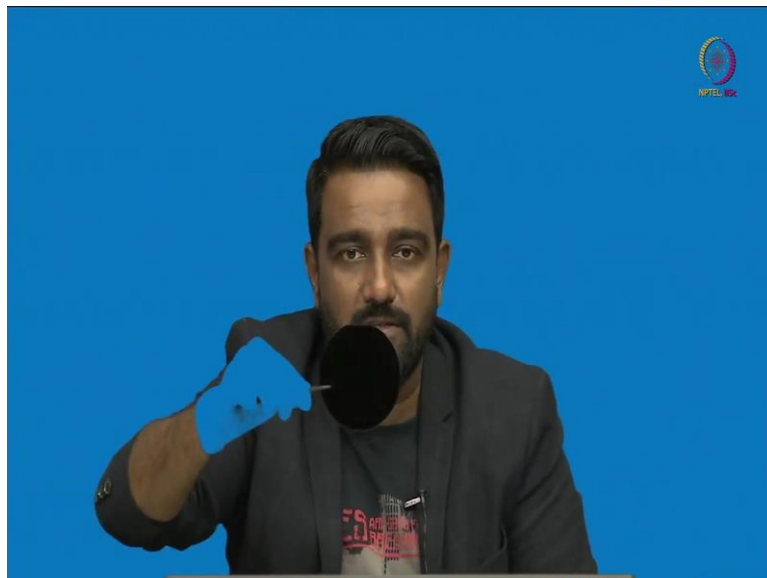
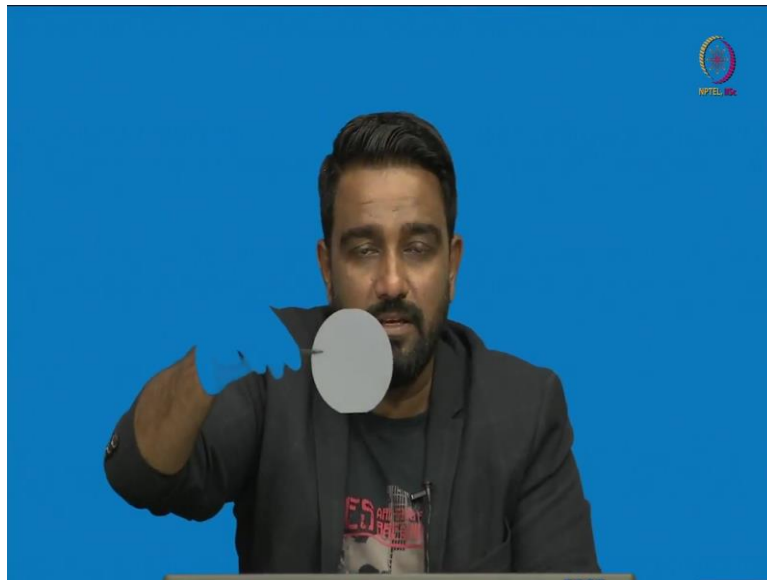
How does this look like? Like holding something, it looks like something holding. So, if you so, let us let us correlate in the daily activity. I hope that every one of you has in some time in your life have ate roti. So, to hold the roti, and to twist it like to put it on the second surface, the bottom layer top layer, we hold it. And that is a bigger tweezers. It is not called tweezers 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 contamination on to the silicon wafer. Second is you should use tweezers, there is a way to use tweezers, you should not press too much. You should not, you should have enough force to enough pressure to hold a silicon wafer.

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 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. This is the 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 this small flat here, you may not be able to see very clearly but there is a primary flat here, secondary flat here.

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Now, let me show you the backside of the silicon wafer, how does it look 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 boule, when you slice it, lap it, polish 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. 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 cleaning the wafer to remove the contaminants, but additionally there is a single side polish wafer that we know and double side polish wafer.

In double side polish wafer, both the sides would be equally polish. In single side polish wafer, you do not have that. Now, suppose I had touched my sleeves right now, can I hold the wafer again? No. First is if I am using something I should not touch my clothes. But this is something is this 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 touch, 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 that 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 in front of us clean clothes as to show it to you. So, I am not going out but the point is these are the silicon wafer looks like single side polished, double sided polished, 4-inch wafer, primary flat, secondary flat 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, N-type wafer, 100 or 111.

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**Thermal Oxidation Methods of Silicon**

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  
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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 oxidation. In this technique, what you have? Your oxygen and you have nitrogen and you have silicon, where are silicon wafers, silicon wafers are here. And a silicon wafers are placed in what, silicon wafers are placed in a furnace.

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### Thermal Oxidation Methods of Silicon

DRY OXIDATION

WET OXIDATION

PYROGENIC OXIDATION

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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  $SO_2$  and then this one here circle with a cross is a valve.

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### Thermal Oxidation Methods of Silicon

DRY OXIDATION

WET OXIDATION

PYROGENIC OXIDATION

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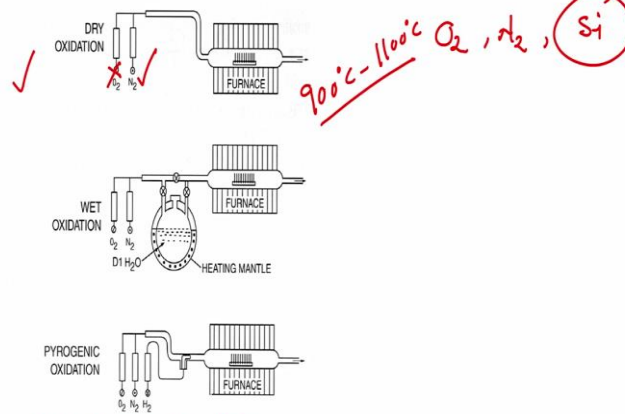
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## Thermal Oxidation Methods of Silicon



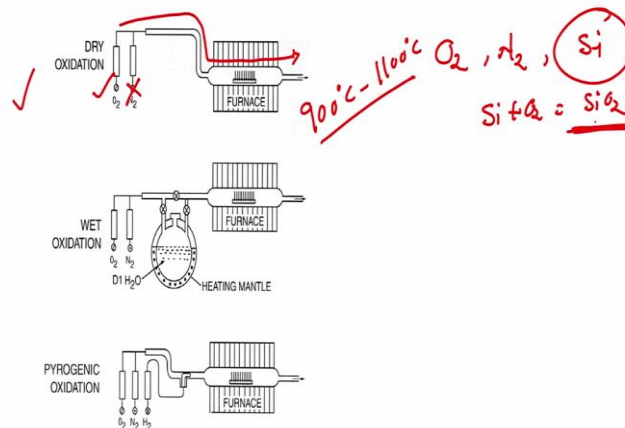
Wet oxidation using H<sub>2</sub> and O<sub>2</sub> is more popular (cleaner) than using H<sub>2</sub>O vapor.

Now, let us understand first the dry oxidation technique which is the first one. Here what happens is initially when this 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 this 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 that region as a carrier gas.

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

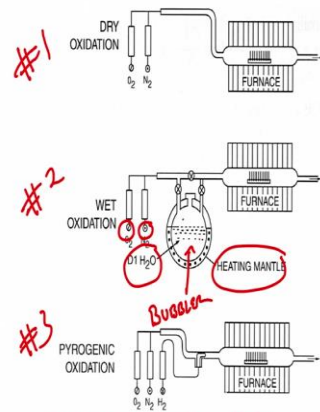
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## Thermal Oxidation Methods of Silicon



Wet oxidation using H<sub>2</sub> and O<sub>2</sub> is more popular (cleaner) than using H<sub>2</sub>O vapor.

## Thermal Oxidation Methods of Silicon



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

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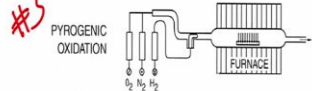
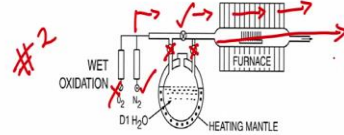
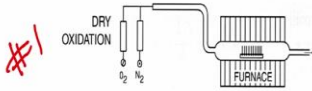
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Now, you close the nitrogen and let the oxygen flow through this. So, close the nitrogen, open the oxygen let the oxygen flow through the furnace and comes out. When this happens then there is the formation of silicon plus oxygen use  $SiO_2$ , there 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.

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 oxygen technique we have nitrogen, we have oxygen. We have  $H_2O_2$  there is a heating mental and that means this will form a bubbler, bubbler. So, when you heat the water what will happen? Water will convert to water vapor, heavy formation water vapor, water vapor is there.

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### Thermal Oxidation Methods of Silicon

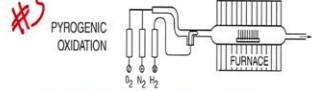
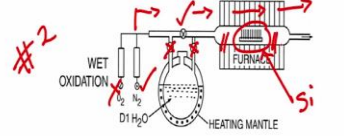
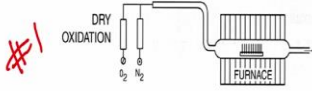


Wet oxidation using  $H_2$  and  $O_2$  is more popular (cleaner) than using  $H_2O$  vapor.

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### Thermal Oxidation Methods of Silicon



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

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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 then reason of nitrogen also is to purge is to remove the excess oxygen which may be there in the furnace, because there is a air, air contains oxygen. So, just purging the air out of the furnace is also the role of the nitrogen.

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### Thermal Oxidation Methods of Silicon

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

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

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Now, once you place the silicon wafers in the presence of nitrogen gas in the furnace and you have a tube the temperature which you want for thermal oxidation, then what you do the next step? 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 vapor which is there in the bubbler it will carry the water vapor inside the furnace and then this is a silicon wafer and silicon wafer plus  $H_2O$  gives  $SiO_2$  plus  $H_2$  balance equation  $O_2$ , so  $2H_2$ , here  $2H_2$ ,  $2H_2O$ ,  $2H_2O$  a better equation is balanced. This will be the byproduct or the so, hydrogen will come out and silicon dioxide is formed using the wet oxidation technique. This is a very efficient technique.

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### Thermal Oxidation Methods of Silicon

#1 DRY OXIDATION

#2 WET OXIDATION  
DI H<sub>2</sub>O HEATING MANTLE

#3 PYROGENIC OXIDATION

Wet oxidation using H<sub>2</sub> and O<sub>2</sub> is more popular (cleaner) than using H<sub>2</sub>O vapor.

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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 a water vapor 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.

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### Thermal Oxidation Methods of Silicon

#1 DRY OXIDATION

#2 WET OXIDATION  
DI H<sub>2</sub>O HEATING MANTLE

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Wet oxidation using H<sub>2</sub> and O<sub>2</sub> is more popular (cleaner) than using H<sub>2</sub>O vapor.

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Now what will happen that we will open H<sub>2</sub> will open, O<sub>2</sub> will close N<sub>2</sub>, then this O<sub>2</sub> will mix with H<sub>2</sub> here and this forms the H<sub>2</sub>O and or H<sub>2</sub>O<sub>2</sub> because H<sub>2</sub> and O<sub>2</sub> this both forms the water vapor H<sub>2</sub>O, we will balance equation later and then the silicon is there, so there forms a

silicon dioxide again. This is way cleaner and more popular rather than using the water vapor which is  $H_2O$ .

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**Thermal Oxidation Methods of Silicon**

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This way you can grow silicon dioxide faster also. But the best quality amongst all this three thermal oxygen 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 these NMOS or whether this PMOS, combination of NMOS and PMOS, which is CMOS.

We have the transistors that are formed where there is a source as 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

#1 DRY OXIDATION

#2 WET OXIDATION

#3 PYROGENIC OXIDATION

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)

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Now, you will see here the photo of the chamber so, there are two furnaces these are called horizontal furnace and vertical furnace. It is very easy. The furnace are placed horizontally, apart furnace are placed vertically. The vertical furnace are not that popular compared to horizontal furnace.

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### Thermal Oxidation Methods of Silicon

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#2 WET OXIDATION

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

Vertical furnace (not popular)

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Also we can have three different for furnace, furnace 1, 2, 3. So, what we call is a 3 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 will have this zone 1, zone 2, zone 3.

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

So that is the advantage of having the 3 tube horizontal furnace with multi zone temperature control. If you want to read, 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 that an oxidation is performed.

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### Thermal Oxidation Equipment



The diagram illustrates the components of a thermal oxidation furnace. It shows a horizontal quartz tube containing silicon carbide (SiC) rods. Heating coils are wrapped around the tube. Gases enter from the right (inlet) and exit from the left (outlet). An end plate with a seal is at the left end. The flow velocity of the gases is denoted as  $v$ .

- 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  $1\text{cm/s}$ .

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Now, this schematic, sorry this photograph shows an engineer working in a cleanroom and if you see she is placing the horizontal 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 had to push this inside the furnace so you can use a silicone rod, silicon carbide rod, silicon carbide can withstand very high temperature.

So, you can push this wafers into the furnace in the presence of nitrogen and then you close the nitrogen and start oxygen or  $\text{H}_2$  plus  $\text{O}_2$  or  $\text{H}_2\text{O}$  vapors, we have seen that. So this is this deoxidization of the same. Silicon wafer you have already seen how it looks like and I have shown it to you one single wafer. These are and we have discussed in previous lectures that there is always a batch fabrication, not like one wafer after second wafer after third wafer 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 vapor flows to the reactor and pass the silicon with a typical velocity of one centimeter per second.

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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

The diagram illustrates the thermal oxidation process. It shows a quartz tube furnace where silicon wafers are pushed in with a nitrogen gas flow. The oxidation process occurs at 900°C to 1100°C with a flow of oxygen or water vapor. The wafers are then taken out with a nitrogen flow. A graph shows the temperature profile across the furnace, with regions A, B, and C marked. A handwritten note 'PHOTO LITHO GRAPH PATTERN' is present. Below the graph, three silicon wafers are shown, labeled 1, 2, and 3, with increasing thicknesses of silicon dioxide ( $SiO_2$ ) on their surfaces.

<https://pubs.rsc.org/en/content/articlehtml/2019/cp/c9cp03305j> 28

So it is a super easy technique to understand once you understand the concept and if you want to see the steps. So, these are the same steps 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 in with nitrogen gas flow which we already know.

Oxidation process is between 900 degrees centigrade and 1100 degrees centigrade with the flow of oxygen either is dry oxidation or water vapor which is wet oxidation and wafer are taken out with the nitrogen flow. So again when you are, when you finished the oxidation cycle, you need to start the nitrogen again, let the furnace cooled 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 the 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 a choice. Now we want to create a step that means using photolithography, I will etch silicon dioxide from this region, you can see here. So, I

will use the photography 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, 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.

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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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### Thickness Measurement Surface Profilometry: Mechanical

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

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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 this 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. In a single side polish, what is the roughness? If the double side polish what is the roughness?

If it is 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 toughness 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 oxygen the oxide will grow on both the sides.

So, what is why it is grow on both the sides? You can see this surface and the back surface both are in contact with oxygen, 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 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 oxides ZnO, then what is the roughness, what is this roughness here that you see like this wavy lines side, what is the roughness of this? That if you want to measure the roughness then there is a technique called Atomic Force Microscopy - AFM, and that is what is done here.

AFM also can be used for thickness measurement. In AFM instead of using the diamond tip which is here we use silicone cantilever. Now what is cantilever? Let me give an example and everybody 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.

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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.

Traveling stage, Scanning line, Stylus, 2  $\mu\text{m}/\text{mm}$  slope, Mirror image of stylus

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

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Traveling stage, Scanning line, Stylus, 2  $\mu\text{m}/\text{mm}$  slope, Mirror image of stylus, Stylus, Source, Detector, Si, SiO<sub>2</sub>, SiO<sub>2</sub>

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

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So suppose assume that this is a diving board and there is a person here diving into the water in the water, what is this thing, this plank? This becomes a cantilever, is not it? So in silicon wafer, if you want to fabricate a cantilever then you can form a cantilever like this, with a tip, with a tip like this.

Now this tip, so if I have silicon dioxide, silicon, 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, source and detector, so light falls and 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 is 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 the 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**

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

Traveling stage  
Scanning line  
2  $\mu\text{m/mm}$  slope  
Diamond

Mirror image of stylus

stylus

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

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And 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 silicone dioxide means you are etching silicon dioxide from the remaining area, so create a step.

But then that wafer or that device or that that portion of the wafer will be 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

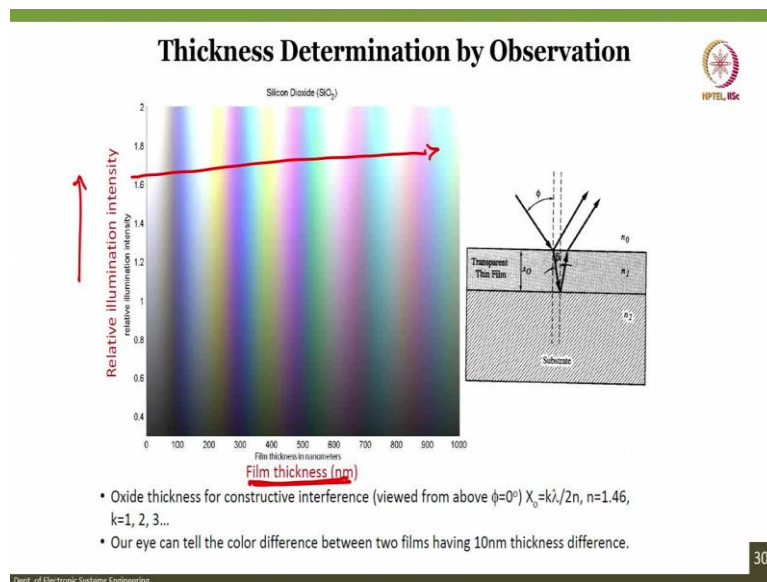
roughness of the material. But if you if you see the mechanism there is a travelling stage, these are travelling stage which is here then there is a stylus, generally stylus is diamond tip diamond and then there is a scanning line and then there are steps.

So, what happens is it will just form like this and this change 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, zoom in, what we want to see in real time display scale, you want to see 100 percent zoom in image, you have x-y stage, you can manipulate the x-y 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 nanometer, 200 nanometer, 0.1 micron, 0.2 micron, if you want to know the roughness, you can measure, if you know the thickness you measure.

So, roughness measurement mostly the atomic false microscopy is used where I told about the cantilever mechanism.

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So now, if you see the screen again in this case what you observe is that you see the color, color 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 color, you can see the color change and that is the oxide thickness for constructive

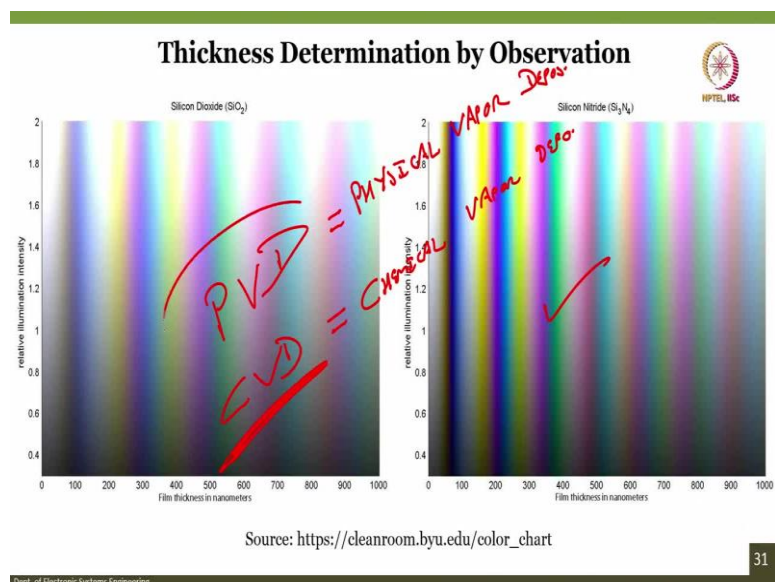


interference. You know that constructive interference versus destructive interference can be given by the situation where you have  $n$  equals to 1.46 and  $k$  can be from 1 to 3 and so on.

So I can tell you the color difference between 2 films having 10 nanometer thickness that is the limitation of our eye that they can tell you with 10 nanometer thickness again if you are working from many years into a 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 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 that 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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Now, view 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 nitrite 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, vapor or vapour both spelling are okay deposition. And CBD will be chemical vapor deposition.

So in CVD, using CVD technique, you can grow silicon nitride, you can spot a silicon nitride as well with PVD but the rate of sputtering is extremely low, you can also sputters silicon dioxide again the using sputtering technique. So, there are advantages and disadvantages of

physical vapor deposition and chemical vapor deposition, we will go into detail in some in one of the lectures.

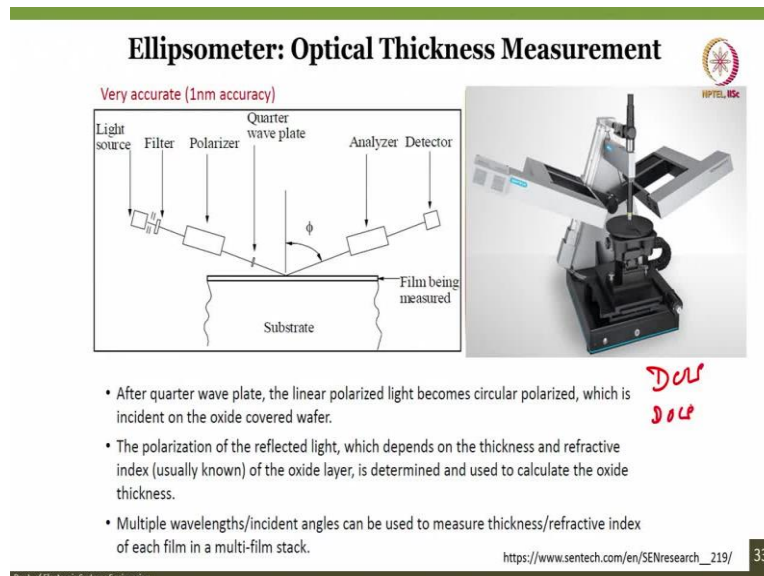
So, again when it comes to silicon nitride also you can kind of understand the form of the color for the intensity you can understand what should be the thickness of the silicon dioxide.

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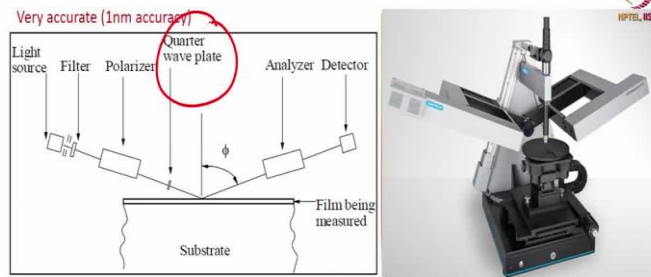


So in reality it is this complicated. So, you see that from tan all the way to blue-violet how the thickness changes and how the colored bands are there. Same thing goes for blue all the way to 9900 thing which is orange. So, generally when you see basically conduct oxide or oxidized silicon wafer, you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

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## Ellipsometer: Optical Thickness Measurement



- 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.

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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, Ellipsometer or Ellipsometer the it is optical thickness measurement technique, is an extremely accurate one 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 on the film that is being measured and then it passes through the analyzer and finally to the detector. Now, the after the quarter wave plate the linear light 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 the 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 polarized or 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 wavelength is analyzed can be used to measure the thickness refractive index of each film in a multi film stack.

The 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 destruct the wafer is not a destructive technique, but there is some limitations. So, find out the limitation of this particular tool. So, with this we will 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 non-destructive technique.

How the colors would change depending on the thickness of silicon dioxide, what is red oxidation, what is the oxidation, what are the tube 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, this all things we have seen and now we know that there is some there is a substrate which is silicone and then we have an insulator which is silicon dioxide.

Till now, we have just seen this first step which is your silicon wafer and silicon wafer is your 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 in 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 projects. So, with that, I will stop here. I will see you in the next class. Till then. Take care. Bye. Cheers.