Fabrication Techniques for Mems-based Sensors: Clinical Perspective

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Lecture – 05

Silicon, silicon di-oxide and photolithography contd

Welcome to this module and in this module we will be looking at how we can grow silicon dioxide and what is the characterization method to understand or to measure the thickness of the grown oxide.

In the last module what we have seen, we have seen the importance of silicon dioxide or you can say the application of silicon dioxide such as a masking oxide, a gate oxide, pad oxides and also it can work as a mask against diffusion, against dopant right. Either it is a diffusion method or it is a ion implantation method.

So, we also saw how we can grow oxide depending on the either we are using a wet technology or we are using a dry technology. So that means that if we use vapour, then we have a wet oxidation; if we just use oxygen, we have a dry oxidation. And advantage of dry oxidation over wet oxidation when it comes to the quality of the oxide.

Now, again in a wet oxidation and dry oxidation, the growth is done in a furnace. It is the net high temperature around 900 degree centigrade to 12 1100 degree centigrade. So, when you talk about furnace if the furnace is vertical it is called vertical tube furnace. If the furnace is horizontal is called horizontal tube furnace alright. So, this is done in a horizontal tube furnace.

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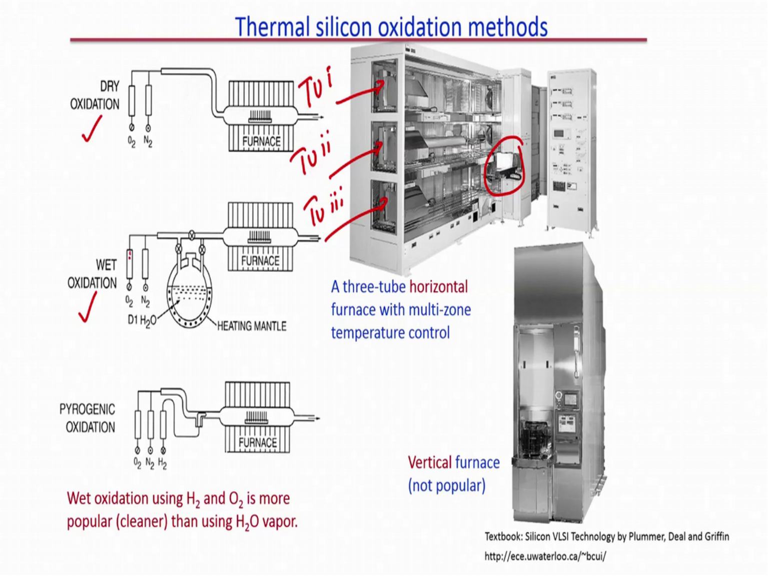

Thermal silicon oxidation methods

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

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

Vertical furnace (not popular)

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

So, if you see the screen, you can see thermal oxidation methods. First one is a dry oxidation where you can see that when we have to load first stage is you have to load the wafers inside the furnace. Now when you are loading the wafers, you have to purge out the unwanted oxygen, because we do not want to start grow growth of oxide at lower temperature until all the wafers are at a particular temperatures to have a uniform growth.

So, we will first introduce nitrogen and we will purge out the oxygen and other gases from the chamber only nitrogen would be there. Now we will insert wafers right or a wafer holder; wafers will be kept on a wafer holder. The wafer holder would have slits to hold the wafers like slits to hold the wafers. So, if you see a cross section, you will just see like this alright which is shown here.

So, that is why whenever we see oxide, oxide grows on both the surfaces front and back oxide grows on both surfaces front side of the wafer and the backside of the wafer whether it is polished or unpolished, it does not matter; it does not matter.

Second now this is about, so once the furnace reaches at a temperature. Let us say 1,100 degree centigrade. We will stop nitrogen and we will start flowing oxygen; we will stop nitrogen and we will start flowing oxygen. So, that silicon dioxide forms on the silicon wafer; so, first thing. Second is wet oxidation. In wet oxidation, there is a bubbler this we can say bubbler or a heating mantle is the outside this is a heating mantle here right and there is a water inside the bubbler. Now we heat this water and the vapours are created.

Now initially, this valve is closed, this valve is opened and this valve is closed. So, oxygen cannot pass only nitrogen is allowed to pass right. So, nitrogen flows into the chamber similar to this process right.

And once we reach a appropriate temperature say 1100 degree centigrade, then what we do? We keep this open, we stop nitrogen, we start oxygen; we stop this or close this valve open this valve and open this one. So, what will happen?

Now, the oxygen will flow through this to the bubbler, it will take the vapour out vapour will go up and it will reach the chamber to form the oxide got it right. So, here we are using vapour which is vapour which is H 2 O gas alright to create a oxide and this is your wet oxidation.

Another one is pyrogenic oxidation where you allow the H 2 to react with O 2 and form H 2 O and then you know when the oxygen is flowing you allow H2 to pass through it react it and then, you can grow oxide. However, pyrogenic oxidation is not so popular like dry oxidation and wet oxidation. So, we will just concentrate on dry and wet oxidation we will not consider pyrogenic, we will not talk about it later.

Now, this are the actual photograph of the horizontal multi zone furnace used to grow thermal oxide on silicon wafer. This is horizontal tube furnace sorry this is horizontal furnace; this is vertical tube furnace this one is horizontal furnace one and number two is vertical tube furnace. Vertical tube furnaces are not too popular in growing silicon dioxide. So, we will concentrate on horizontal tube furnace.

Now, in horizontal tube furnace there are three zones a three tube horizontal furnace with multi zone temperature control see tube 1, tube 2, tube 3 right; tube 1, tube 2, tube 3 three tube and multi zone. We will see in the next slide; you can control the temperature, you can program the temperature right using your system and you can grow multiple oxide thickness a multiple thickness of oxide one thickness can be on tube 1, second would be on tube 2, third would be tube 3. So, the throughput increases the throughput would be high.

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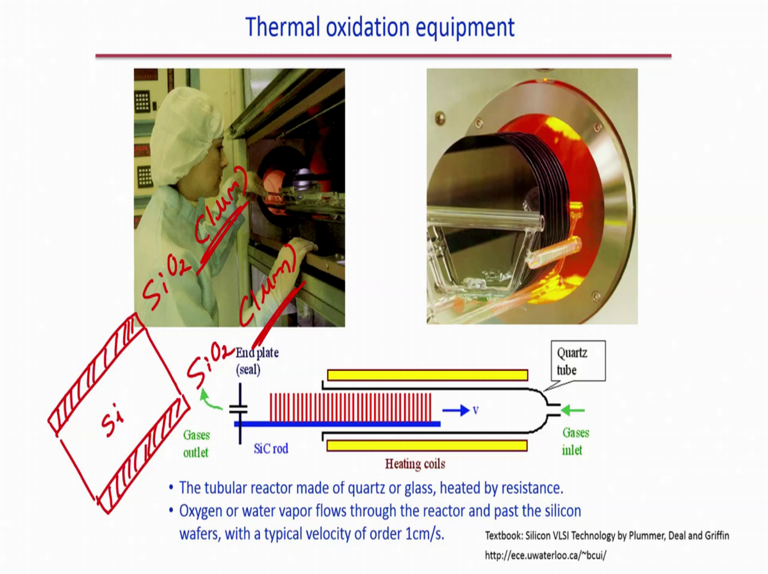

Thermal oxidation equipment

- 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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Now, you can see here we have a we have wafers loaded onto the wafer holder. And this wafer holder is inserted inside this horizontal tube furnace. It is already heated right and you can here see that operator is pushing the wafers inside the horizontal tube furnace right. Now the tube is generally made up of quartz; the gases are inlet from one side gases are the outlet is on another side right and the silicon rod is used to push the wafers inside the horizontal tube furnace.

The typical velocity of oxygen or water vapour that flows through the reactor is around one centimetre per second alright. This is a typical velocity for the oxygen or water vapour to flow through the reactor.

So, once we have a oxide, let us say I have silicon wafer and what I said that the oxide will grow on both the sides because gases react with both surfaces of the silicon wafer right. You see here both surface of silicon wafer the gases react with both surface forming oxide on both side. So, once we have oxide grown on the silicon wafer right, silicon dioxide.

Now, we have optimized the parameter; let us say we have optimized a parameter and we have grown 1 micrometer of silicon dioxide. How you know it is 1 micrometer? How you know it is 1 micrometer?

So, to understand to measure the thickness of silicon dioxide we have to use some characterization tool, thickness measurement tool correct. So, what are those tools? So let us see.

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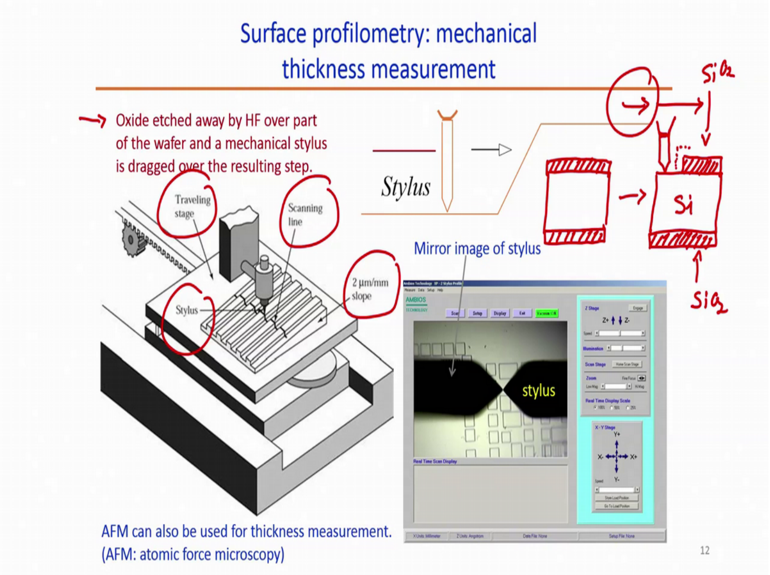

Surface profilometry: mechanical thickness measurement

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)

The first technique is called a surface profilometer in which it is also called alpha step profilometer in which we use a stylus to scan the wafer and get the thickness. However, we need to perform a process before we can use stylus to measure the thickness, what is this process.

So, let us see here let us say this is the wafer and we have oxide. Then before we use stylus we have to create a step in the oxide we have to create a step in the oxide using photolithography. I will I will teach you photography in the following lectures right now just see that there is a step. We have removed oxide from this surface and we are retained oxide in this area right. In this area we have removed and in this area we have retained the oxide right.

Now, what we will do? Now we will take this stylus and we will scan the wafer with the stylus. So, what will happen when it goes here? There is a step; there is a step right there is a step here. So, because of this step, the stylus will bend and as corresponding bending of the stylus will be calculated and that will be your z direction right, and corresponding to that we can know the thickness of the silicon dioxide.

So, you can see here oxide etched away by HF hydrofluoric acid over part of the wafer and mechanical stylus is dragged over the resulting step. There is a travelling stage right there is a stylus here and there is a scanning line through which stylus is scanning there is a 2 micron per millimetre slope right. And you can here actually see the photograph of a styler mirror image of a styler here; a stylus here And you can see it is scanning through the stage and when it scans through the stage it can give us the; we can change the speed of scanning, we can change the speed of the z direction, illumination, scan stage, zooming

whether you want to have a display at 100 present, 50 percent 25 percent and you can calculate the thickness of the oxide. So, you can it is very easily understand that if I move this stylus from this direction to this direction, you can see my pen moving here right. So, from this to this direction there is a step, because of this step we can know the thickness.

However the this way of measuring the thickness of the silicon wafer comes with some kind of drawbacks. And drawback is that it cannot measure the thickness of silicon with ultra precision accuracy, precise value. And for example, with the precision of 1 nano meter or 2 nano meter or 10 nano meter scan it cannot do. So, it can be used for crude measurements.

Now this is still better, but sometimes in a lab, you will you will observe that just looking at the wafer you can tell it is 1 micron or it is 0.5 micron. Because the colour of the wafer would change since the silicon is light gray in colour or you can say little bit darker light lighter gray or gray in colour and then you grow 1 micron oxide, you will see a greenish colour of silicon.

So, let us see if I have a wafer I can show it to you can see this one, this is purple in colour; you can see very clearly purple in colour right. So, this thickness of oxide is different in this case thickness of oxide is different in this case you see this one.

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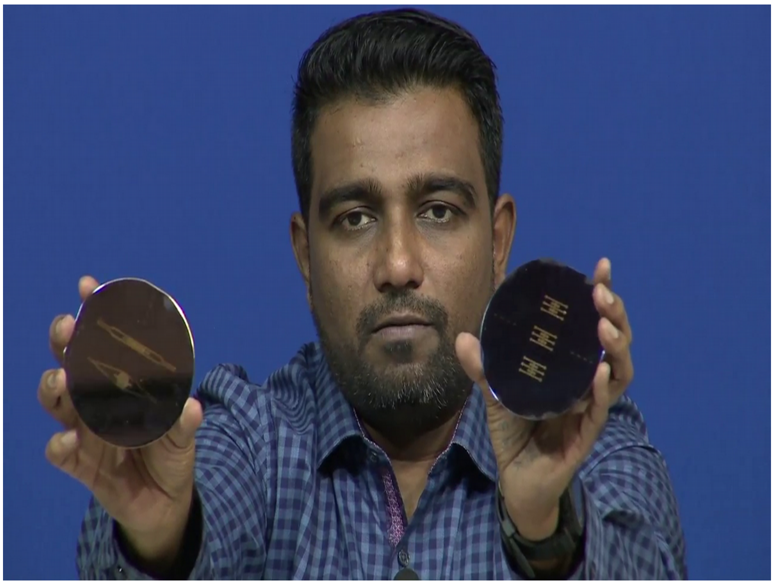

See this is how the silicon colour would be greyish. So, if I put now this one you can clearly see a difference when a oxide is grown right. Difference when the oxide is grown you can clearly see the difference in colour right, do not worry about the pattern just worry about the colour. Silicon oxide on silicon, very easily you can identify correct backside is oxide of course.

So, in here we have etched the oxide from the front side here it is there; in here there is a oxide on the front side oxide on the back side; oxide on the front side oxide on the back side alright. Here no oxide on front side, but there is oxide on the back side. So, now what is the thickness of oxide, I cannot tell what is the thickness of oxide just by looking at the colour of oxide. Or if I am working from long time in a laboratory with the experience, I can tell it can be 0.5 micron it can be 0.8 micron or close to let us say it us 1 micron, but how accurate I am with my thickness is not possible.

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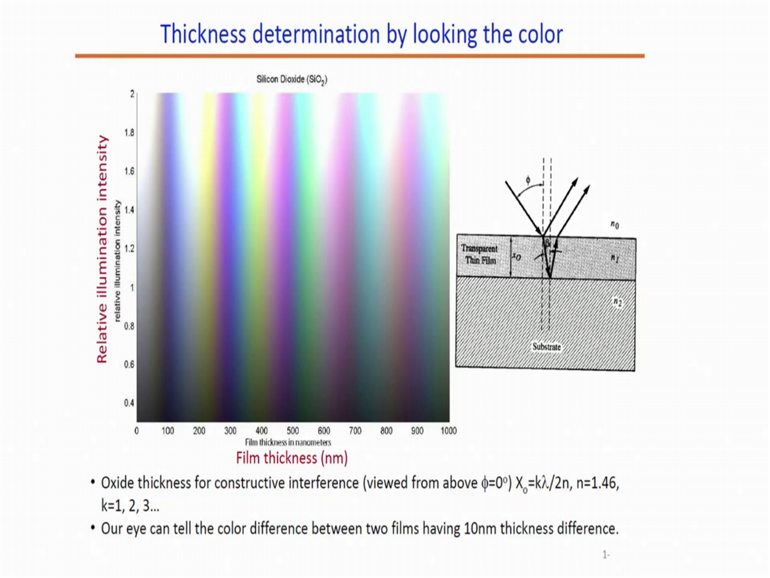

Thickness determination by looking the color

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

So, you see here the thickness determination by looking the colour, relative illumination intensity right silicon dioxide. When you grow silicon dioxide you can really clearly see here because of the transparent thin film the oxide thickness for constructive interference viewed from about angle 0 degree is x 0 equal to k lambda by 2 n, n equals to 1.46 for k equal to 1 to 3. So, I can tell the difference between two films having ten nanometer of thickness difference. However, it is very difficult to exactly differentiate ten nanometers, but like I said about 200 nanometers difference 0.2 microns we can tell if it is if we have enough experience working in the lab.

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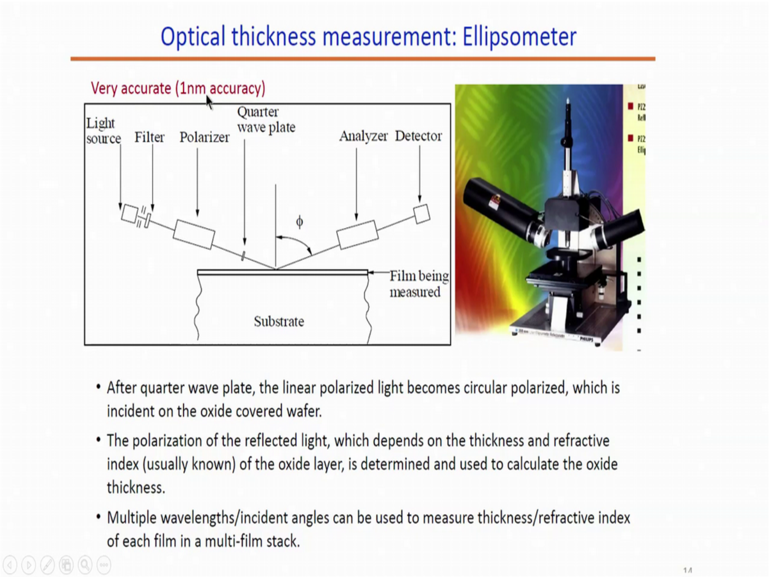

Optical thickness measurement: Ellipsometer

Very accurate (1nm accuracy)

- 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.

So, what to do? Then to have an extremely precise measurement of the thickness of silicon, we have to use something called ellipsometer the technique is called ellipsometry and the equipment is called ellipsometer where there is a light source, filter, polarizer, quarter wave plate; there is a reflection, there is analyzer and detector the film is measured. So, after the quarter wave plate the linearised, so after when you insert the light after the quarter wave plate, the linearized linear polarized light becomes circular polarized which is incident on the oxide right. And the polarization of light which depends on the thickness and refractive index of the oxide layer is determined and used to calculate the oxide thickness. Now, multiple wavelengths incident angles can be used to measure thickness or RI of each film in a multi thin multi film stack.

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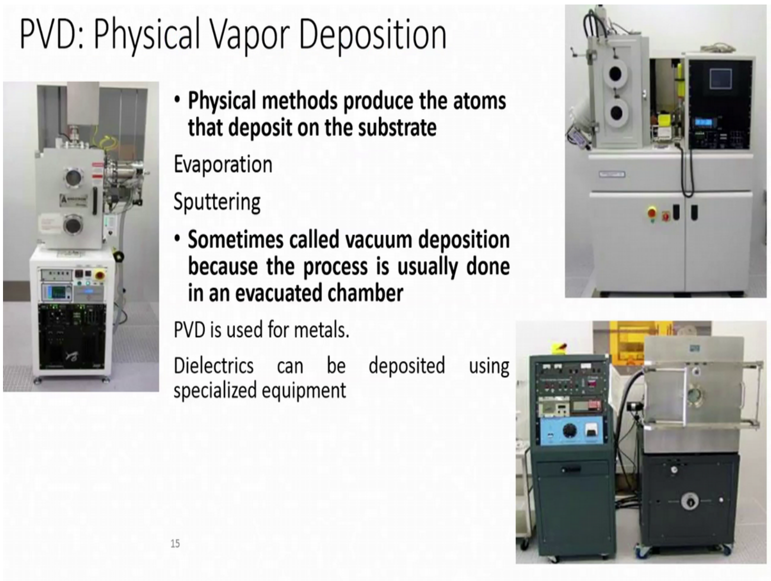

PVD: Physical Vapor Deposition

- **Physical methods produce the atoms that deposit on the substrate**

Evaporation

Sputtering

- **Sometimes called vacuum deposition because the process is usually done in an evacuated chamber**

PVD is used for metals.

Dielectrics can be deposited using specialized equipment

The advantage of this particular technique is its accuracy of 1 nanometer, 1 nanometer accuracy. So, this is what we have to understand that when it comes to measuring the thickness of oxide, we have a few techniques starting from alpha step profilometer or surface profilometer, we can understand using the colour of the wafer or we can use ellipsometer to understand the thickness of the wafer.

Now in the next class, let us see what is physical vapour deposition. It is very important because we want to understand what is photolithography; but for performing photolithography, first we let us see what is silicon, silicon dioxide, physical vapour deposition, then we move to photolithography. Till then you take care I will see you in next class bye.