Integrated Circuits, MOSFETs, OP-Amps and their Applications

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Lecture – 06
Introduction to fabrication technology

Hello, welcome to this particular module and in earlier modules, what we have seen? We have seen how to fabricate an interdigitated electrode in an SU-8 well and, in my last class what I taught you? I have shown you how to fabricate a gas sensor. So, in both the cases the idea was that we understand what is the micro fabrication process and if you have noticed one thing in both the devices one was your interdigitated electrodes IDEs within the SU-8 well and another one was sensor, in both the devices the starting wafer was silicon and on that silicon wafer, what we have grown, we have grown silicon dioxide.

So, the point is what is a process or what is the equipment that is used to grow this silicon dioxide and whether the silicon dioxide is actually used when we are going to fabricate a MOSFET, whether we are going to use the silicon dioxide? That is another question. So, if we are going to use silicon dioxide and in which part of the MOSFETs we can use silicon dioxide.

So, we have to understand, what are the techniques or what is that particular technique that is used to grow silicon dioxide? I told you to understand and remember the some words when you talk about the process flow; one, is you have the substrate we have seen different kind of substrates, then another one is we are growing silicon dioxide, another one is we are depositing metal, another one is we are spin coating the photoresist, then we are developing the photoresist, there is a UV exposure, then there was a etching of metal and there is tripping of photoresist.

So, these are a few terms that we have to remember because that is actual technical terms used when you understand micro fabrication all. So, having said that let us see what are we going to do today.

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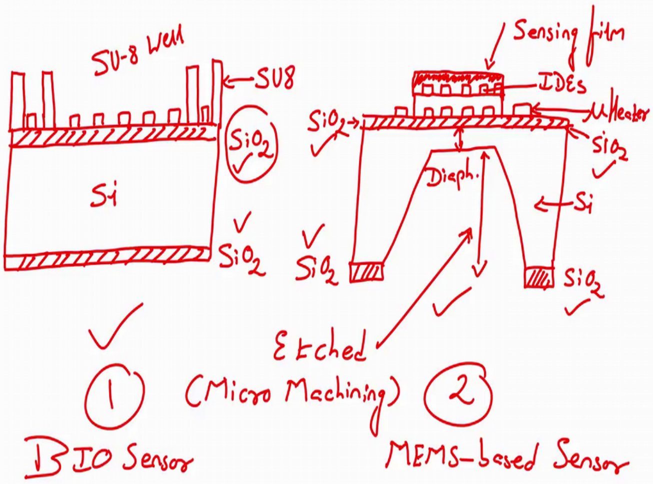

Today, we are learning the thermal oxidation process. So, if you come back on the screen and if you focus the thing that. We have seen until now I think that we have seen until now are 2 devices; one is an interdigitated electrodes in an SU-8 well and in both the cases what we have seen, there is silicon substrate and there is silicon dioxide. This is SU-8. This is first device that we have seen, number 1.

Second device, what we saw was a sensor with a micro heater, on which there was insulator, on which there were interdigitated electrodes, on which there was sensing film. This is your interdigitated electrodes, this is your micro heater, this is silicon, this is silicon dioxide and this one is diaphragm. So, in both the cases, whether it is a sensor or whether it is an interdigitated electrode, this is also we can call bio sensor. This is MEMS based sensor; because we have done here, what we have done? We have etched this much area, we have etched this. So, this is also called when we etch this much we are machining if you go to workshop and if you want to remove this much material from a metal, this much material which is shown here from a metal plate then we can we have to machine that part. Here, we are machining at micro scale. So, it is also called micro machining.

So, the point that I am making here is that in both the cases one thing that we have seen is the silicon dioxide. We have seen silicon dioxide which is grown silicon dioxide, which is grown on the substrate, the substrate is silicon. In this case it was silicon, now this much we have learned. Now, what we have to see is how this silicon dioxide we can grow. So, in this particular lecture we are focusing on. So, now, you see we are moving towards understanding the integrated circuits how we can fabricate or how we can fabricate a MOSFET and then we will go to the op-amp and then we will see their applications. I have lot of experiments for you guys to see how we can use operational amplifiers and form several circuits.

I also show you how MOSFET looks like, how op-amp looks like, what kind of equipment we require to actually demonstrate the use of the op-amp, whether it is an oscillator or whether it is a multi vibrator, again is a part of oscillator or the offset characteristics or the characteristics of op-amp, offset input voltage or input bias current, input offset current, how we can understand the virtual ground, how inverting amplifier can be used, how non inverting amplifiers can be used, how filters can be used. There are several type of filters that I have as a part of the experiment that I will show it to you from several filters low pass filter and high pass filter, band pass filter, main deject filter, then we have some simulation to for you to show.

So, this is how it will help you to understand how we can apply the knowledge of your integrated circuits, your MOSFETs, your op-amps into actual kind of circuits and how you can really design the circuits, how you can design the circuits and how you can check the circuits, how you can evaluate the circuits. So, that will be part of the experiment series which is part of this particular course. So, not only you will learn the basics of how to fabricate or how to design a process flow for fabricating a MOSFET, but you will also learn along with understanding the op-amps that how you can apply those op-amps, how you can apply this knowledge into the experimental designs.

So, coming back to this particular lecture we will look in this lecture thermal oxidation. So, next 2 lectures we will be focusing more on the fabrication part and then sometime around the end of the another 2 lectures you will be able to understand how you can fabricate a MOSFET or how you can at least draw the process flow for fabricating a MOSFET. So, let us see here what kind of thermal oxidation we can perform.

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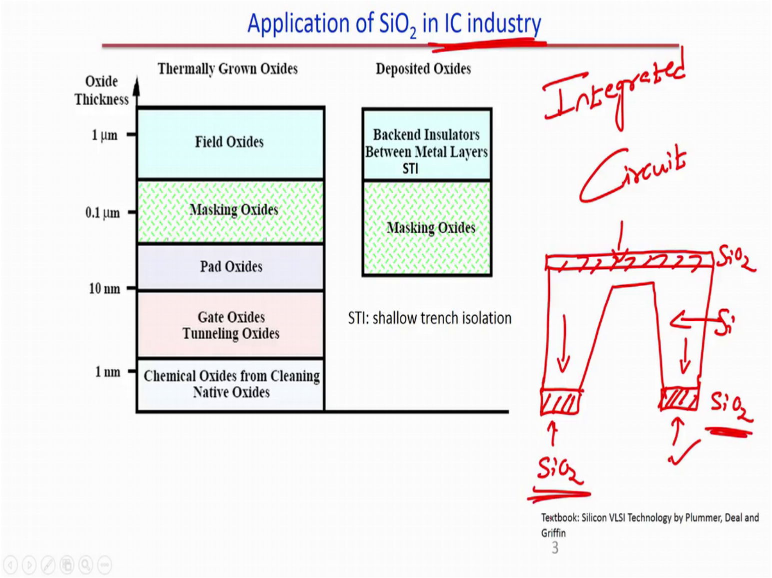

Application of SiO_2 in IC industry

STI: shallow trench isolation

Textbook: Silicon VLSI Technology by Plummer, Deal and Griffin

What we see? The first thing that we see is that in the IC industry; what is IC industry? Integrated Circuit industry. In Integrated Circuit industry, what we find? We find that you can change depending on the thickness of the oxide you have different applications. Now, you see if you can see on the screen, what you see is that if you want to use the thermal oxidation or SiO 2, you can use it as a thermal oxide or you can use it as a filled oxide if your thickness is around 1 micron, you can use as a filled oxide. If a thickness is around 0.1 micrometer you can use as a masking oxide.

Now, we have seen example of masking in the fabrication that when we wanted to etch the wafer from the backside, what we have done, we created what we grown we have grown silicon dioxide and then the silicon dioxide we have grown correct and then what we have done? We have created a window. What was the window we created in the backside in the second example like this and then I told you that now we can etch it using wet. So, the silicon we can etch using wet or dry etching. This I had told you in the last class. So, when you etch silicon nothing happens to this particular layer or the silicon below it this. The silicon below this SiO 2, this is your SiO 2 and then the rest of the sensor is or on the top is here.

So, here, when we dip this wafer in either wet or dry etching say either we perform wet etching or we perform dry etching what will happen, the silicon will get etch if it is dry etching we will have the something similar structure. If it is wet etching then we will obtain a diaphragm which looks like. This angle created is 54.7 degree when you are using wet etching, but the point is that if we use SiO 2, this silicon here is not getting a effected, it is not getting etched. If you use SiO 2 here the silicon here is not getting etch; that means, this silicon dioxide acts as protecting oxide, it can protect this layer from getting etched. So, this is what the purpose of the oxide can be.

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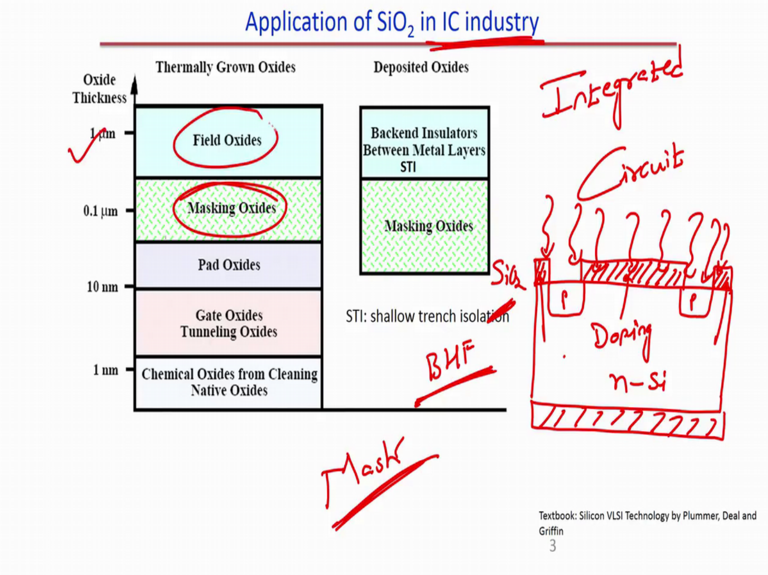

Application of SiO_2 in IC industry

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Another way is when you want to deposit, when you want to create the diffusion layer diffusion. So, or NNP type of diffusion, let us say this is n type wafer and you want to create a p type for source and drain. So, these areas if you remember for the MOSFET this is dopants, source and drain. How you will create source and drain? So, in this case for creating source and drain what we will do, we will have the oxide, this is n type silicon we will have oxide on top and on bottom and then we will open the window; that means, we will remove the oxide using our photolithography technique that is your spin coating and then pre baking and then exposing with the mask and then unloading the mask, then developing then post baking and then etching the silicon dioxide. I also told you to etch silicon dioxide we can use BHF, it is Buffered Hydrofluoric acid. This is the acid that we can use to etch the silicon dioxide.

So, the point is that if I have if I have this SiO 2 and if I want to diffuse now, diffuse or ion implant the source and drain region, then I will do the ion implantation like this or diffusion any process you can use then this area which is protected by the oxide this area which is protected by oxide, this area which is protected by oxide, this will not get diffused. See the dopant cannot enter this, dopant cannot enter this silicon dioxide or it will not a silicon dioxide will protect the silicon from getting diffused because it will act as a mask.

So, I have shown you 2 ways; one, we can use the silicon dioxide as a mask in sensor. Now, this is a silicon dioxide that that you can use the mask during the doping of p or n type source or drain and that is why SiO 2 if it is around 0.1 micron this can also worked as a masking oxide. So, first role we have seen of silicon dioxide, field oxides; second role of silicon dioxide masking oxide; third role of silicon dioxide is to use as a pad in the pad oxides, third is for the pad oxides.

Then, we have fourth role which is somewhere between 10 nanometer and 1 nanometer we can use this as a gate oxide or tunneling oxides. You know that in MOSFET we when we when we theoretically understand MOSFET what we see there is a thin layer of gate oxide we say like this thin layer of gate oxide, what is thin layer of gate oxide? What is the value? It is around 1 to 10 nanometer we have to understand, it can also vary depending on type of MOSFET and with the technology advancement, it will change. The point is when we learn MOSFET when we say thin layer you can always say is between 1 and 10 nanometers somewhere around this value. So, the thin layer of oxides can also be grown using the thermal oxidation.

What is the next step? 1 nanometer to that level, now, you understand the importance of the dimensions. I told you one single hair, the thickness of one hair human hair is around 80 to 100 microns or 70 to 100 microns; 1 millimeter is 1000 microns.

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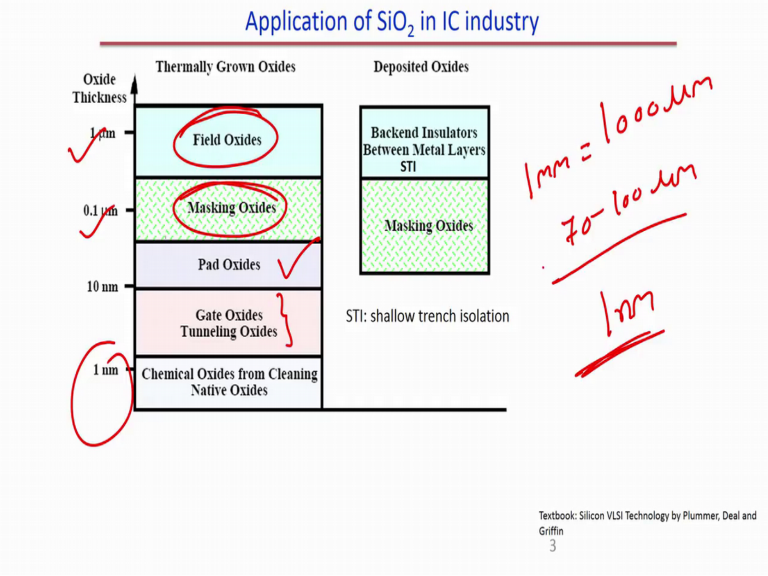

Application of SiO_2 in IC industry

Thermally Grown Oxides

Deposited Oxides

Oxide Thickness

1 µm

0.1 µm

10 nm

1 nm

Field Oxides

Masking Oxides

Pad Oxides

Gate Oxides
Tunneling Oxides

Chemical Oxides from Cleaning
Native Oxides

Backend Insulators Between Metal Layers
STI

Masking Oxides

STI: shallow trench isolation

Textbook: Silicon VLSI Technology by Plummer, Deal and Griffin

Now, what I am saying is human hair is about 70 to 100 micrometers, you see and what we are talking about we are talking about 1 nanometer. So, it is extremely thin. For this, we can use as a chemical oxides from cleaning native oxide. So, if this is the case if you want to remove the clean the native oxides the chemical oxides from the native oxides we can have thickness of about 1 nanometer.

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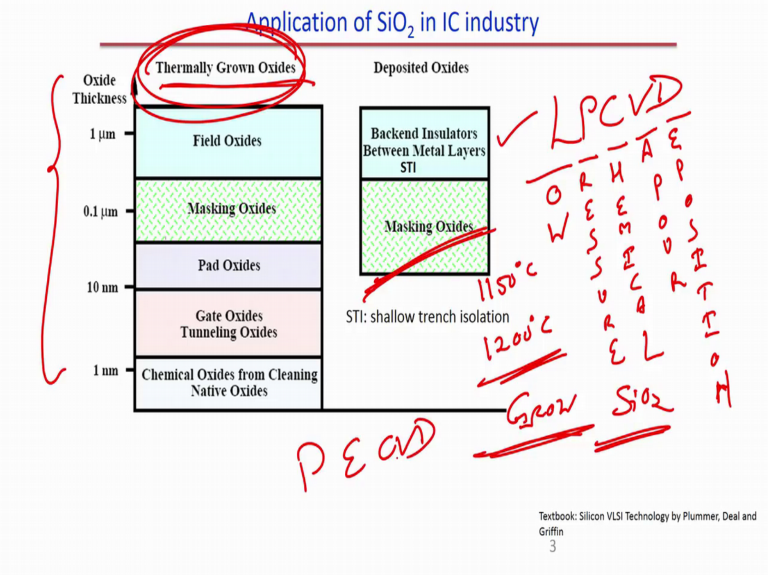

Application of SiO_2 in IC industry

Thermally Grown Oxides

Deposited Oxides

Oxide Thickness

1 µm

0.1 µm

10 nm

1 nm

Field Oxides

Masking Oxides

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Now, if you talk about deposited oxides, this is thermally grown oxides, another one is deposited oxide. So, what is deposited oxide? This is thermally grown oxides and we can see we can vary the thickness of the oxide from 1 nanometer to 1 micron. How about, I want to deposit the oxide. So, one is backend insulators between metal layers and STI, metal layers in a STI. So, backend insulators between metal layers means if I want to have if I have a metal and I have to have another metal then if I want to have some separation, I will separate it with some oxide material. I have separation with the oxide material. So, it can act as a insulating material between 2 metals. You understand in this term that can act as an insulating layer between 2 metal layers and of course, the another operation of this or the use of this deposited oxide is again as masking oxides is again as masking oxides.

So, there are 2 things that we had to remember one is called LPCVD - Low Pressure Chemical Vapor Deposition. Low Pressure Chemical Vapor Deposition this is carried out at 1150 degree centigrade to 1200 degree centigrade. This is to grow silicon dioxide, thermal grown oxide. Second one is called PECVD.

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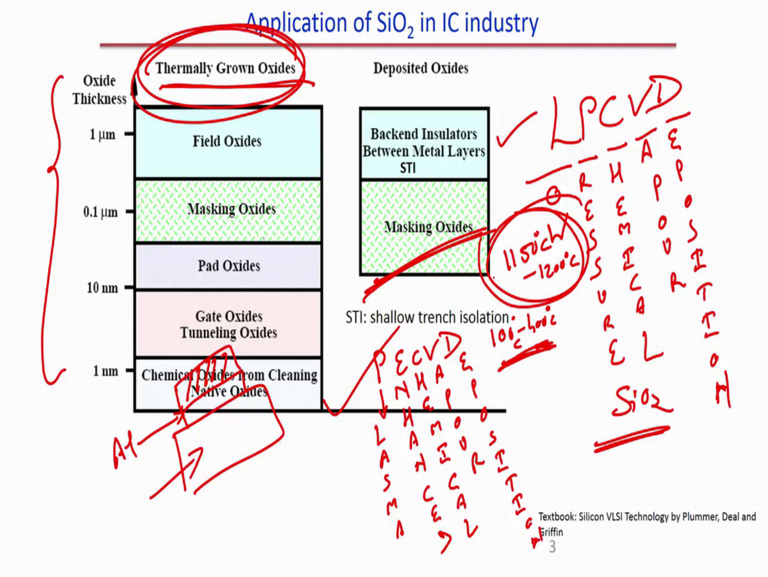

Application of SiO_2 in IC industry

Thermally Grown Oxides

Deposited Oxides

Oxide Thickness

1 µm

0.1 µm

10 nm

1 nm

Field Oxides

Masking Oxides

Pad Oxides

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Chemical Oxides from Cleaning Native Oxides

Backend Insulators Between Metal Layers STI

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Textbook: Silicon VLSI Technology by Plummer, Deal and Griffin

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So, we will write somewhere here PECVD. Plasma Enhanced Chemical Vapor Deposition. PECVD, this can be done from 100 to 400 degree centigrade; that means, the temperature required here was 1150 degree centigrade to 1200 degree centigrade, temperature require is between 100 to 400 degree centigrade, that is why whenever we have a material which is sensitive to temperature and which can get affected by higher temperature in this particular range we can go for Plasma Enhanced Chemical Vapor Deposition. Easy, high temperature no worry about the substrates beneath it, we can use LPCVD; for example, if we take a silicon we do not worry about silicon nothing will happen to silicon at 1150 to 1200 degree centigrade.

So, we do not really worry that it will get destroyed, no. But, if you have aluminum suppose you have aluminum; on aluminum if you want to grow oxide then you cannot grow oxide at 1150 or 1200 degree centigrade, aluminum will melt. You got an example. So, the point is there are 2 types of oxidation; one is when we grow it, one when we deposit it. When we grow it another one is when we deposit it. When you grow it you have different application of the growth grown silicon dioxide one is your field oxide, the another one is masking oxide, another one is pad oxides, another one is gate oxides or tunneling oxides and the last one is your chemical oxides, from chemical native oxides and then finally, you have from cleaning the native oxides and finally, you have backend insulators between metal layers and you have masking oxides.

So, this is the application of silicon dioxide in an IC industry.

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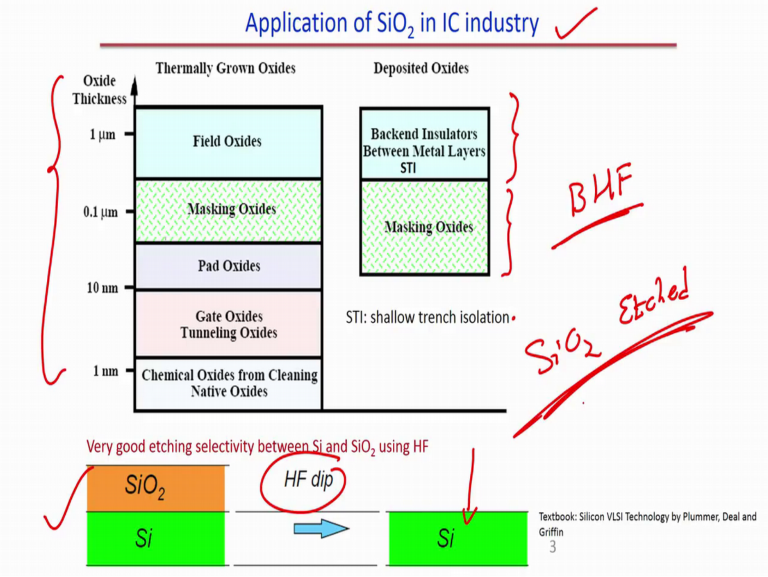

Application of SiO_2 in IC industry

STI: shallow trench isolation

Very good etching selectivity between Si and SiO_2 using HF

Textbook: Silicon VLSI Technology by Plummer, Deal and Griffin

Now, let us move to the next one. So, very good etching selectivity between Si and SiO 2 using HF. If I have a silicon dioxide on silicon which is this one and if I dip it in HF, I told you we can use buffer hydrofluoric acid or we can use hydrofluoric acid, if we dip it what we will find, only silicon. Silicon dioxide will get etched SiO 2 without affecting silicon. Silicon will not get affected. Good, now let us move to the next slide.

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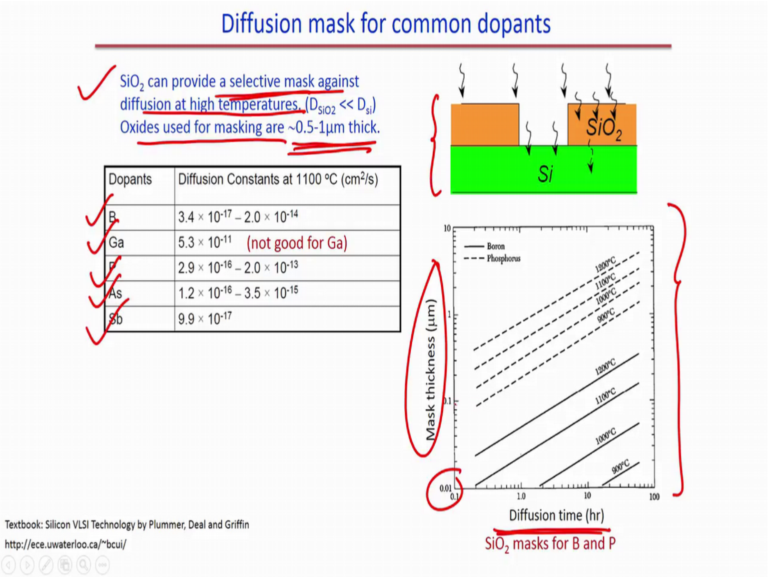

Diffusion mask for common dopants

SiO_2 can provide a selective mask against diffusion at high temperatures. ($D_{SiO2} << D_{Si}$) Oxides used for masking are ~0.5-1µm thick.

Dopants	Diffusion Constants at 1100 °C (cm^2/s)
B	$3.4 \times 10^{-17} – 2.0 \times 10^{-14}$
Ga	5.3×10^{-11} (not good for Ga)
P	$2.9 \times 10^{-16} – 2.0 \times 10^{-13}$
As	$1.2 \times 10^{-16} – 3.5 \times 10^{-15}$
Sb	9.9×10^{-17}

SiO_2 masks for B and P

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

What is next slide? So, what are the diffusion masks for common dopants. It can act as a diffusion mask you know what are diffusion masks if the silicon dioxide can act as a diffusion mask for common dopants. What does it mean? You see silicon dioxide, if you have layer, let me show it to you here, if I have a layer, you understand my palm is one layer my by this hard drive is another layer. So, this is silicon and this is silicon dioxide all. So, what will happen, if I show you this way, what will happen the area which is covered by silicon dioxide if I diffuse it then the area below it area which is by my hand area palm area that is considered as silicon this the hard drive a silicon dioxide then the silicon will not get diffused in the area covered by silicon dioxide; that means, silicon dioxide acts as a mask for the dopant. For the dopant, the silicon dioxide will act as a mask, very easy.

Now, what kind of common dopants we can use. So, if you go back to the screen, you will find that there are several common dopants that are boron, Ga, phosphorus, As, Sb, arsenide and then you can see silicon dioxide can provide a selective mask against diffusion at high temperature oxides for masking which is about 0.1 to 1 micron. Here, you can see the mask thickness and can grow the silicon dioxide for the diffusion. For the diffusion time hour is there, a 900 degree you need this much thickness you want to have 1200 degree for boron and phosphorus both what is the thickness that is required for the silicon dioxide, on this particular silicon to act as a mask for the dopant. Common dopants are the most common dopants are boron and phosphorus to create your n channel and p channel for your MOSFETs.

That means, now we understood that the silicon dioxide is extremely important part when we talk about a MOSFET.

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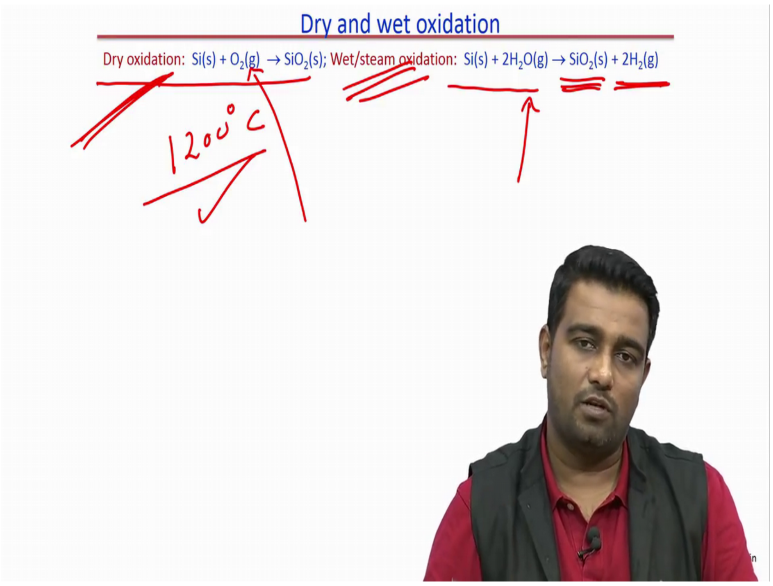

Dry and wet oxidation

Dry oxidation: $Si(s) + O_2(g) \rightarrow SiO_2(s)$; Wet/steam oxidation: $Si(s) + 2H_2O(g) \rightarrow SiO_2(s) + 2H_2(g)$

So, let us see the next slide and you see here that if you come back to the slide what do you see here there are 2 types of oxidation; one, is a dry oxidation and another one is a wet oxidation. When you talk about dry oxidation you have silicon you have a wafer at very high temperature about 1200 degree centigrade and loaded into a thermal furnace, I will show it to you how the furnace looks like and you pass oxygen onto the heated wafer which is silicon, then the oxygen will react with silicon to form silicon dioxide.

You see, here we have used oxygen directly we have not used water vapor; that means, we have used a dry oxidation technique, but if I have the silicon wafer at high temperature in the horizontal tube furnace and if I inject the oxygen in forms of water vapor; that means, I take a oxygen I pass it through the bubbler in which water is there and it is heated. So, the water vapor will be carried to my. In that case, I have silicon reacting with what is water vapor H 2 O, it is finally a H 2 O. So, when I balance my equation what will I have silicon plus 2H 2 O will give us SiO 2 plus 2 H 2.

This technique is called wet oxidation, this technique is called dry oxidation; that means, that we know 2 types of oxidation, one is dry oxidation, and one is wet oxidation.

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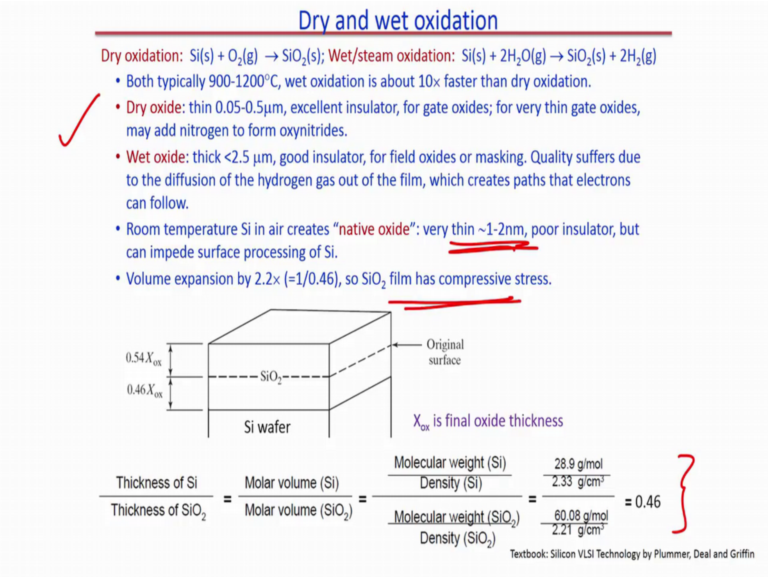

Dry and wet oxidation

Dry oxidation: $Si(s) + O_2(g) \rightarrow SiO_2(s)$; Wet/steam oxidation: $Si(s) + 2H_2O(g) \rightarrow SiO_2(s) + 2H_2(g)$

- Both typically 900-1200°C, wet oxidation is about 10× faster than dry oxidation.
- Dry oxide: thin 0.05-0.5μm, excellent insulator, for gate oxides; for very thin gate oxides, may add nitrogen to form oxynitrides.
- Wet oxide: thick <2.5 μm, good insulator, for field oxides or masking. Quality suffers due to the diffusion of the hydrogen gas out of the film, which creates paths that electrons can follow.
- Room temperature Si in air creates "native oxide": very thin ~1-2nm, poor insulator, but can impede surface processing of Si.
- Volume expansion by 2.2× (=1/0.46), so SiO_2 film has compressive stress.

X_{ox} is final oxide thickness

$$\frac{\text{Thickness of Si}}{\text{Thickness of SiO}_2} = \frac{\text{Molar volume (Si)}}{\text{Molar volume (SiO}_2)} = \frac{\dfrac{\text{Molecular weight (Si)}}{\text{Density (Si)}}}{\dfrac{\text{Molecular weight (SiO}_2)}{\text{Density (SiO}_2)}} = \frac{\dfrac{28.9\ \text{g/mol}}{2.33\ \text{g/cm}^3}}{\dfrac{60.08\ \text{g/mol}}{2.21\ \text{g/cm}^3}} = 0.46$$

Textbook: Silicon VLSI Technology by Plummer, Deal and Griffin

So, let us go to the next slide or the next part of this particular slide and that is that both of these oxidations are done at 900 to 1200 degree centigrade both of these oxidation are carried out at 900 to 1200 degree centigrade, where wet oxidation is about 10 times faster than dry oxidation.

So, the dry oxidation, where it is used? These are the application of dry oxidation and wet oxidation. First you understand dry oxide. Dry oxide about thin 0.05 to 0.5 micron is an excellent insulator for gate oxides, for very thin gate oxides we may have to add the nitrogen to form oxynitrides. Now, we do not have to worry about this particular the complexity of the wet oxidation. What we understand is the oxide can be used if it is a dry oxidation we can use it for the gate oxides and if it is a wet oxidation then the thickness will be less than 2.5 microns, but it is greater than 0.5 micron, then it is a good insulator for field oxides one, for masking second.

But, the disadvantage of wet oxidation is that the quality of the oxide suffers due to diffusion of the hydrogen gas out of the film which creates paths that electron can flow; that means, if I want to have a thin layer of oxide gate oxide then I cannot use wet oxidation because it may have the pin holes through with the electron can flow and this pin holes are created by the hydrogen gas coming out of the film because, now you have Si plus 2H 2 O gives SiO 2 plus 2H 2. So, in the case of gate oxide we should go for dry oxidation, in the case of field oxide or the masking oxides we can use the wet oxidation.

So, let us go to the next part of the slide. Now, room temperature silicon creates in air creates a native oxide. So, if you just keep the silicon in room temperature you will find that there is a thin layer of oxide which is grown which is extremely poor insulator, but can impede the surface processing of silicon; that means, it will affect the processing of silicon; that means, that we have to always start when you have a substrate dip it in HF for 5 to 10 seconds, then you clean it and then you start the process. Do not directly take a silicon and start working on the oxide growing of oxide because what we understand is that even the silicon is at room temperature it will form extremely thin layer of oxide which is poor insulator but, can impede the process; that means, that whenever you take a silicon wafer always dip it for 5 to 10 seconds and then you process it further.

Now, you can see volume expansion of this one is nothing, but 2 by 2 times 1 by 0.46. So, SiO 2 has nothing, but a compressive stress. So, this is just the understanding how we can have thickness by say a thickness of silicon, particularly of silicon dioxide and we find that when we calculate it is about 0.46.

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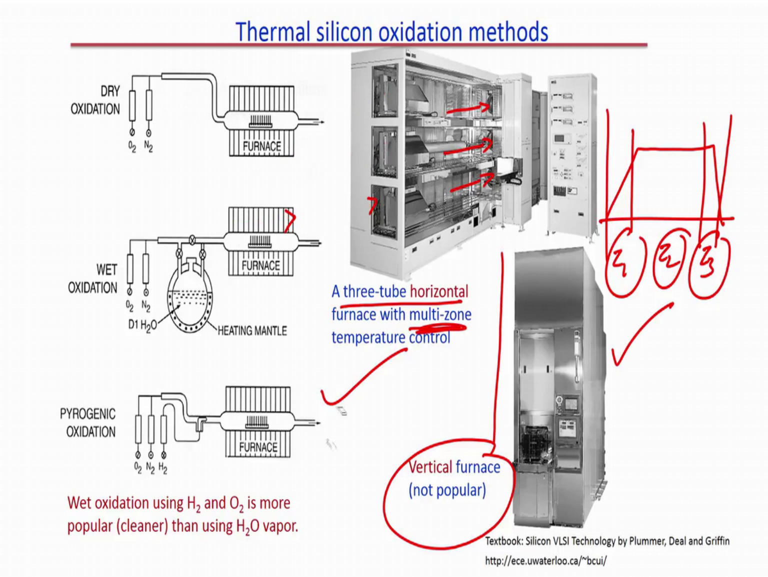

Thermal silicon oxidation methods

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.

Textbook: Silicon VLSI Technology by Plummer, Deal and Griffin

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

Now, what next we have to see? We have to see the thermal oxidation methods. First, is your dry oxidation, second is your wet oxidation, third one is your pyrogenic oxidation. In all the cases, what we see one thing common is, there is a furnace, there is a horizontal tube furnace you see. The tube is in horizontal direction that is why it is called horizontal tube furnace. If tube is in vertical direction, vertical tube furnace; tube is in horizontal direction, horizontal tube furnace.

So, one thing is clear that we require a horizontal tube furnace, second is it is a furnace, so, it should be at high temperature. If it is bubbler involved wet oxidation bubbler is not involved dry oxidation. This other system will look like this our system will look like. So, what we see here is first one is a 3 tube horizontal tube furnace. There are 3 tubes 1, 2 and 3 that you can load inside here and another one is your vertical furnace. We can see that it is in vertical direction, but the point is that vertical furnace is not so popular and horizontal furnace is the extremely popular furnace to grow the silicon dioxide.

And, in this horizontal furnace there is a 3 zone temperature like this we will tell zone 1, zone 2, zone 3, so it is called three-tube horizontal furnace with multi zone temperature control, so, z 1, z 2, z 3. We can control the zone temperature individually control the zone temperature individually. That is not really a part of detailed part of this particular course. So, we do not worry about it, we just understand that for growing the silicon dioxide we can use horizontal tube furnace. This particular technique is also called LPCVD.

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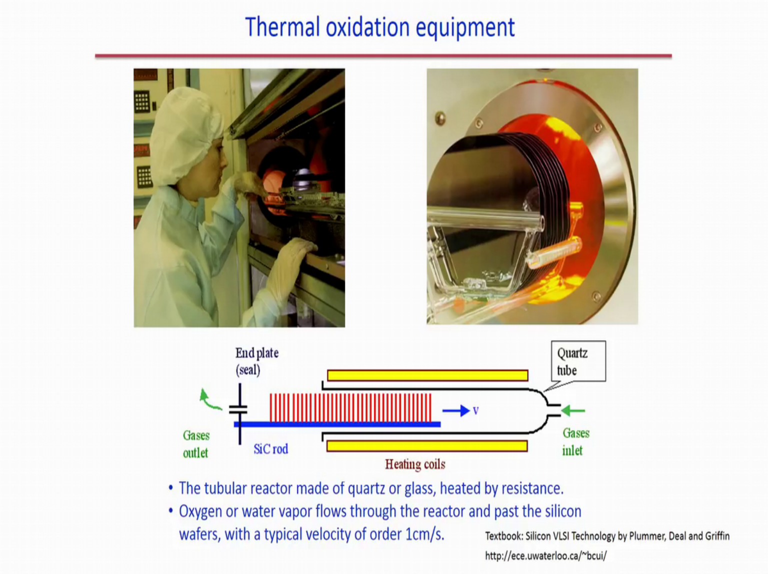

Thermal oxidation equipment

- 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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You can actually see now, that a person is loading engineer is loading the wafer, you can see here set of wafers loaded into the furnace. This is how horizontal furnace or tube furnace looks like we have taken this image from the lecture given by Professor Bo Cui and he is from waterloo. So, I have taken this particular image from his slide and you can see the point was that I wanted you to see you can also see his slides, his presentation that will also help you to understand further silicon dioxide, but that is all about silicon dioxide. I just wanted to take a part where you can fast understand how the thermal oxide is grown all. So, that is why we had taken this particular slide and here you can see very clearly that you have the you have the holder for the silicon wafers and then you can see the temperature is extremely high around 1100 to 1200 degree centigrade and you have to load the furnace inside the, you have to load the wafer inside the horizontal tube furnace.

So, you can see here there is a silicon rod through which you can push the wafer you can we have to push the wafer inside it can be done using the silicon rod by which you can push the wafer and then you have a heating coils, you can have a gas inlet here and this is generally a quartz tube. This is generally a quartz tube quartz can take very high temperature. So, you can see here the tubular reactor made out of quartz or glass heated by the resistance. Resistance is nothing, but your heating coils.

Oxygen or water vapor flows through the reactor and pass the silicon wafers with typical velocity of 1 centimeter per second. This the velocity of the water vapor that we can pass through the silicon wafers loaded inside the horizontal tube furnace. So, now, this is how we can grow the thermal oxide.

So, guys I hope that you understand what we have studied today. What we have studied, if we quickly see once again our slides, we have seen the application of SiO 2. I have shown you 2 examples where we can use the silicon dioxide; one is a biosensor that we have seen, another one is MEMS-based sensor that we have seen and we in both the cases we have used the silicon dioxide, then I have shown you the application of silicon dioxide in IC industry, whereas, the thermally grown oxide or this deposited oxide and by changing the thickness we can apply it for several layers including field oxide, masking oxide, gate oxide, pad oxides and so on and so forth.

We know that the silicon dioxide can be etched using hydrofluoric acid and we have seen that how silicon dioxide can mask, can act as a mask for the diffusion for common dopants and we have seen the common dopants here. The most frequently used dopants are boron and phosphorus.

Then, we have seen the dry oxidation. We have seen how the dry oxidation, wet oxidations are different. How it can be used, in which particular case we had to use dry oxidation when you have gate oxides, thin layer of oxide because wet oxidation creates a path for the electron that can flow and cause a problem in your circuit that is why we cannot use the wet oxidation for the gate oxide. The wet oxidation can be used for the field oxides. Then, we have seen that the SiO 2 is compressive, then we have calculated the compressive. If you have thickness of silicon over thickness of silicon dioxide how you can measure the molecular volume by molecular SiO 2, we have seen this equation and we found that it is nothing, but equals to 0.46.

Then, we have seen the thermal oxidation methods. We have seen horizontal tube furnace and we have seen vertical tube furnace and finally, we have seen the photograph of how the engineer is loading the wafer inside the horizontal tube furnace. We found that the tube is made up of quartz, we also found that the gas inlet we can inc we can induce the gas from here, we can have heating coils and we can have the silicon rod to push the wafer further inside the furnace.

Now, in the next class what we will see? In the next class we will see how PECVD can be used quickly, then we will move on to the deposition technique because in your MOSFET you have to deposit some metal. How you will deposit this metal? Until now what we have seen, we have seen substrate, silicon then we have seen oxide is also there in MOSFET. Now what you have to say we have to see the metal contact. We do the contact in the MOSFET and then we will see lithography quickly and finally, we will see how you can understand the process flow for the MOSFET.

So, with that I hope that today you understood application of the thermal oxide in the MOSFET in particular we have seen gate oxides and field oxides. And, you also now know that the thermal oxidation can be done by wet oxidation or wet oxidation technique and dry oxidation technique.

So, read about it again like I said until we reach the MOSFET, until we finish the MOSFET process flow, have some patience, read it, when you reach to MOSFET process flow and you have any question you can ask me or ask the TEA and we will get you back with your with a possible solution for your curiosity or for your questions all till then you take care and I will see you in the next class, bye.