Introduction to Semiconductor Devices
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Lecture - 6.6
Simplified Band Diagrams of Accumulation and Depletion in MOSCAP

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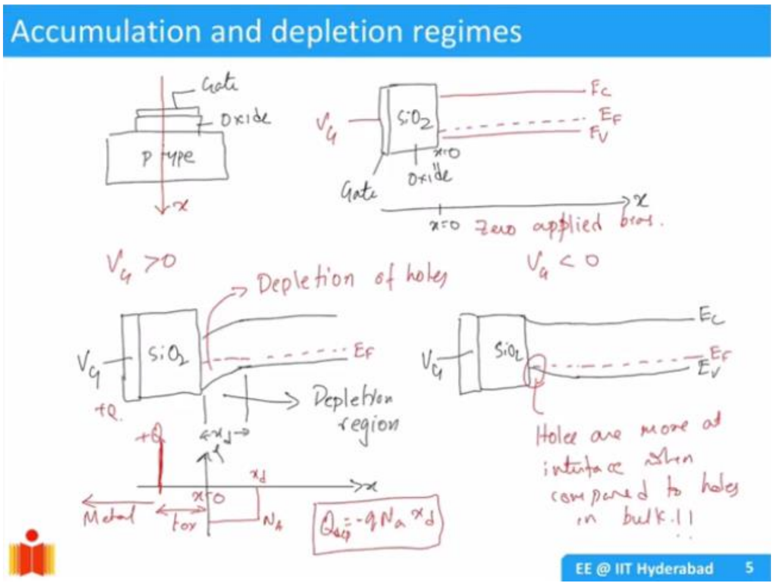

Hello, welcome back. In the last lecture, we have introduced the basic structure of a MOS capacitor. And then we defined what is accumulation, what is depletion. Today, we would like to understand a little bit more about this depletion and accumulation regimes. And we will do that by drawing band diagrams. So, the band diagrams I will be showing you today will be simplified band diagrams.

We will actually draw the complete band diagram in the next week. But for now, let us consider what is you know, the basic MOS capacitor, nMOS capacitor. So, let us say we have a substrate, which is P type. And then I want to have, there is an oxide and then there is a metal on top. This is gate and this is an oxide. Now I want to draw a band diagram as I go from the top to bottom. So, along this axis I want to draw a band diagram.

Let us say this is x. So, how would it look like? To do that fully, we need to look at you know, what are the Fermi level of the gate? What is the band gap of the oxide and then band gap of the silicon? We have to take everything into account. That would be a full and proper thing to do. And we will do that in the next week. But before I do that, today, I want to focus only on the bands in silicon.

That is why I call it simplified band diagram. So, what I will do is, I will try to you know just flip it, and then I will say I will have a gate and then there is an oxide. So, this is my gate. This is my oxide. And for now, I do not really want to bother about you know, what is there in oxide and gate. We will look at it later. For now, I want to just purely look at what is happening in the semiconductor.

So, what I will do is I will draw the bands of a semiconductor. So, this will be my E_C,E_V and then there is a Fermi level. Where is the Fermi level for a p type semiconductor? It should be closer to E_V. So, there should be a Fermi level here, E_F. So, what essentially I am drawing is this is x axis. Well, I mean by x, I mean from top to bottom. Let us say that you know x equal to 0. This is the interface.

Then this is your x equal to 0, silicon dioxide and silicon interface. This oxide will be silicon dioxide in most of the cases for now. So, now we want to draw this band diagram. So, this is essentially without any applied bias, nothing much happens. We are not really worried about Fermi level and the gate right now. We will assume that it is exactly at the same Fermi level as the substrate.

So, we are not even looking showing it. So, now this is a zero applied bias. What happens as I apply a gate voltage? So, if I apply a positive gate voltage, what do we expect? So, if now this is V_G, and you know, there is a, of course, there is a counter terminal in the substrate. We are not showing. This is like semi-infinite in the substrate. So, now, if I apply V_G greater than 0, what did we say?

We said that if gate voltage positive, then that is going to drive the holes away from the interface, silicon, silicon dioxide interface. And then that will create depletion. How will we represent depletion in a band diagram? Well, let us draw it one more time. So, let us say this is your metal. Let us say there is an oxide. I will call it, SiO_2 and this is V_G. You are applying on this. And now it is depleted.

So, what we have to do is, let us if we do not, let us ignore the interface for a moment, and then just draw the bands in the bulk so where you should have a E_F like this. And whatever we did, you know, if you apply a positive voltage, it is not going to drive all the holes out of the semiconductor. It is only going to drive some holes out till you uncover the exact balancing charge. Let us say, this is positive Q.

It will uncover some charge in such way that there is the balancing -Q on the semiconductor side. So, it is depleting in the surface. So, how will we show depletion? Well Fermi level, still it is under equilibrium. So, this has to be this. I mean there will be some shift in the gate Fermi level. We will deal with that later. So, now since we are depleting, the bands have to bend downwards. This is how you represent the depletion.

And so, this distance, I can call it x_d the depletion width or you know x depletion, x_d, which is essentially the depletion width. If you want to call it, call it W. Textbook calls it x_d. So, I am using x_d. So, what is this? This is the depletion region. And how is the charge looking like if I asked you to draw the charge profile of this as a function of x, space charge profile? So, I can draw. I can take my, this is my x.

This is my ρ, if I want to draw. It is a p type semiconductor. We have, well I need to push this up slightly. This is my p type semiconductor. And then I want to draw as a function of x. So, when I apply a positive voltage, what essentially I am doing is at the interface, you know I will call it you know, this is x equal to 0 is the interface. So, and then I will take some thickness you know, this is some thickness t_{ox}. This is oxide thickness.

So, and then there is metal here. You know all this is metal from here onwards. It is all metal. So, when I apply a positive voltage, I get some charge here. This will be +Q which is on the gate right at the interface between gate metal and then oxide. And as what happens in the semiconductor, semiconductor is depleted, but it is a space charge. It is going to have a uniform density here. So, this is my depletion width.

And this will be my N_A. The doping density times the x_d will give you the total charge. So, Q positive or Q is going to be in magnitude.

$$Q_{dep} = -qN_A x_d$$

So, the, on the positive side, you have this. If you want to write Q depletion, then you need to put a minus sign here. So, this is my bands when I am in the depletion regime.

What happens in the accumulation regime? For accumulation regime, we said that, you know, it is a p type semiconductor in the, you know substrate. So, if you want to have more holes, you need to put a negative voltage on the gate. So, what I will do is V_G less than 0. What happens? Now again, the same things I will just draw oxide SiO_2 and gate V_G. And then there is, let us say, there is Fermi level here, E_V and then E_C, and there is a E_F.

So, now, since we applied a negative voltage, V_G is less than 0. It should have more holes at the interface accumulation. How will you represent more holes at the interface? Well, the Fermi level is still the same at equilibrium. Now, the bands will bend upwards. This is indicating holes are more at interface when compared to holes in bulk. So, please make sure that you are convinced about this. You know by looking at this band diagram.

I mean, it is obvious because here, this is the distance. If E_F is closer to E_V, it has more holes. So, when you compare the distance of E_F and E_V, it is more in the bulk and less in the interface. So, you have more holes in the interface. That is why we call it accumulation whereas here in the depletion regime E_F is farther from the E_V. So, you have less holes here. Or, you know rather you depleted depletion of holes. We removed holes from there.

What you have left is some space charge. There are no holes present anymore there, completely depleted. Well, almost completely depleted. So, this is the difference between accumulation and depletion regime in terms of band diagrams. And these are simplified band diagrams. So, let me show you the, you know this is my picture. So, I hope you know it helped you understand the process of drawing these diagrams. I will quickly show you the result.

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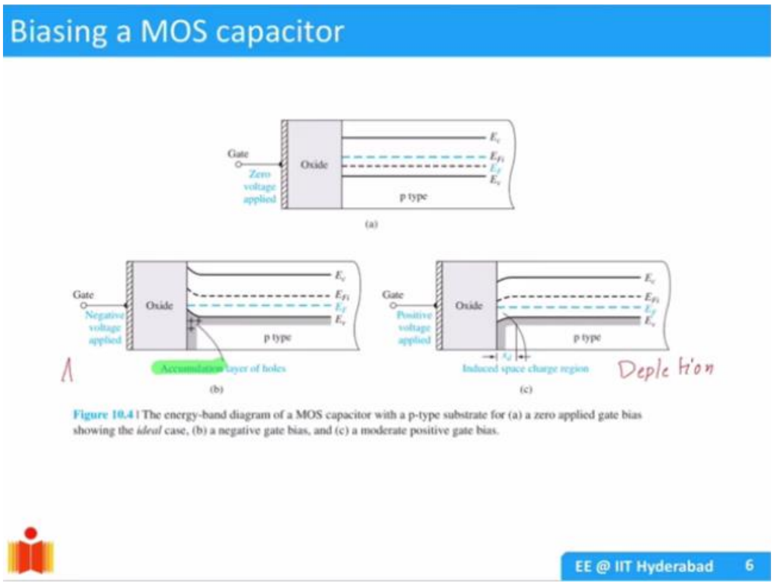

This is from the textbook, you could read up a little bit. And then understand if you are unclear about something here. So, the same thing that, we have been talking about. So, if you have zero applied voltage, your bands are flat, E_C, E_V, E_F and so on. Now, if you apply negative gate voltage, you have accumulation of holes here. And if you have positive gate voltage, we have depletion of holes. So, this is my depletion. This is my accumulation.

So, accumulation of holes, and then there is no applied voltage, there is nothing much happening. So, these are the accumulation and depletion on primary modes we are talking about. In the next video, we will just talk about what is known as inversion. Inversion also is another important property and that plays a very crucial role. That is why I want to talk about it in a separate video. So, I will meet you there. Thank you.