Digital IC Design
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Lecture – 06
Short Channel Transistors – Channel Length Modulation

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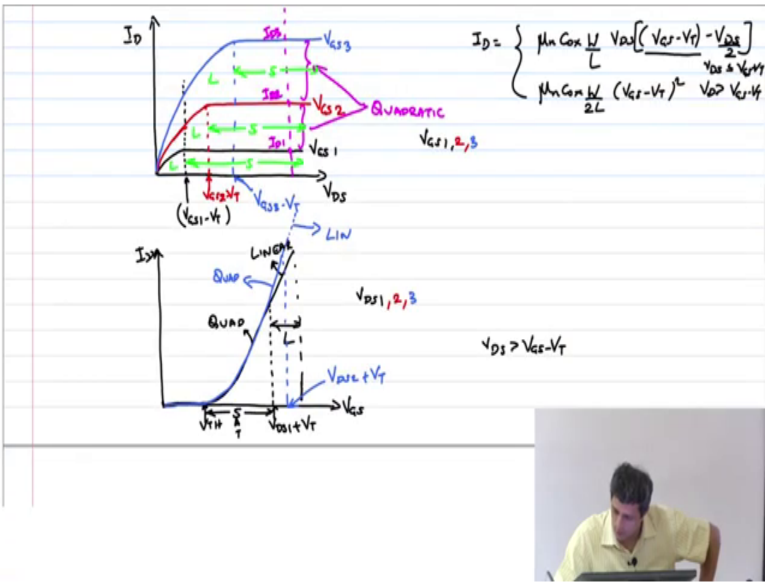

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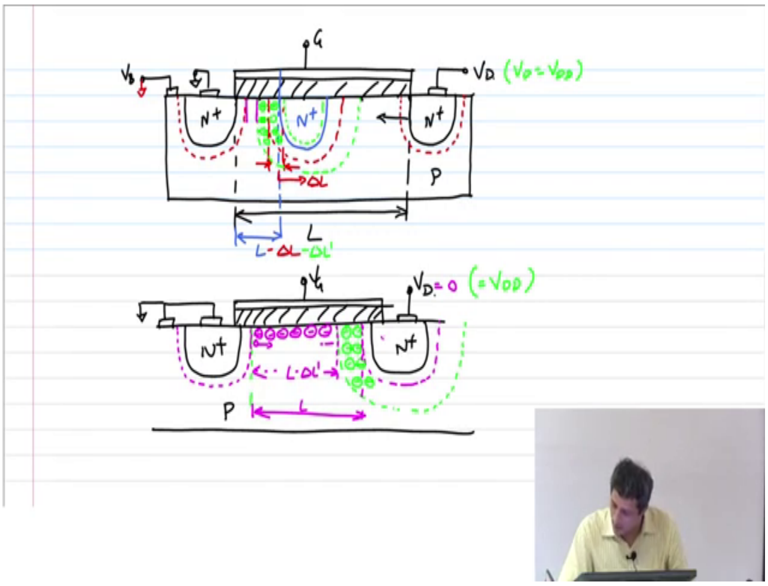

So, now let us look at what we mean by a Long Channel versus a Short Channel device and we will start seeing how the current equation changes, ok. So, first I will try to give you an intuition of why the short channel device should behave differently. I am going to consider I will draw it really exaggerated, ok. Now this is my source, this is my drain and this is going to be my metal and oxide. So, the channel length really is this L, this is N plus N plus P substrate, ok.

Now in order to gain power, speed and other things and also area; people started scaling this transistor, right. So, they started bringing the drain end closer to this source end ok; therefore, they have just simply pulled this guy as close to this as possible ok, N plus and then my gate, alright draw this in blue. So, that it is a different color plus and then I will truncate my gate right here, this is my thing. So, this if you look at it is my short channel device length, ok.

Now consider the various bias conditions that we can apply on this transistor, ok. So, this is the source; source is always assumed to be grounded, because it is a reference potential by definition. Then I have a gate right and I have a drain V D and then I have a body terminal here, right. So, this would be my body terminal actually V B. So, this is a P junction in contact with an N plus junction right that means that, there is going to be a small depletion region or a space charge region around this point of contact.

So, what will happen is, I will have a small space charge region like this; of course, on the source side also it is going to happen, right. Because the channel length was so large, it really did not matter whether I considered the channel length upto this depletion region edge or upto the N plus region; because that distance was negligible earlier. So, it is very easy to define all our terms simply as distance between the drain and the source we did not care for very rigorous definitions there.

Unfortunately, now when we bring this drain very close to the source; the same depletion region would form here as well right; of course, I have changed my supply, I have lowered it. But still what will happen is, now this depletion region that is being formed around the source and the drain will become a significant fraction of the total channel length, right. So, this is if you look at it is basically delta L. So, the channel length will become L minus delta L for whatever reason for the reason that is shown here ok; not for whatever reason, for multiple reasons which I will show you, right.

Now, I will do one more exercise, I will increase this V D to a higher potential from very small voltage 0.1 volt I will make it V D D. Let us assume that the V D D is 1.8 volt. Now what will happen to this depletion region, I know I did not discuss it; but if I forward bias a P N junction, the depletion region will come down. If I reverse bias it, it will go up; this is another thing that we will just take for granted, right. So, is this body source ok; let us assume that the body also is grounded for now by the way, ok. Is this body drain junction forward biased or reverse biased? Reverse biased, right; because I am applying a positive potential to the N plus region and negative potential ground to the P region, ok.

Therefore if I now increase my V D, it makes it worse; because this depletion region will go up further, ok. So, this will become delta L minus another delta L prime, because of my new thing. So, I will say V D V D equal to V D D color coding it, correct. So, now, what happens your channel length has come down already ok; this is just the intuition. By the way channel length has already come down; which means that, my current what will happen to the current, it will increase because its mu and c x W by L, and L effectively has come down. So, it will go up, correct.

Look at the other part, this depletion region is what is going to happen in under the channel. So, what will happen is, there is a depletion region under the channel green here; there is a depletion region that will also form here, correct in the N plus region. If you remember our P N junction picture that I showed you earlier.

But if N plus is in contact with P, the depletion will go far into P region. So, therefore, this guy, the green region will actually go very far into the channel and make it much worse, right. So, what is this depletion region mean; compared to the depletion region that we were forming with a gate. There is really no difference, because here also you already have negative space charge regions here in this P, right.

So, this drain potential that I have applied, positive drain potential that I have applied has caused a depletion region to go into the channel. Already depleting part of the channel and that is a significant fraction if V D is very high now; which means that, what will come down, threshold voltage or transistor will come down.

Now the gate has to effectively invert only this part of the channel; should deplete and invert only this part of channel. Again this is just an intuitive understanding, this does not what happens physically; a physically you have to explain it through energy barriers and all that which is not necessary for this course. Just understand the intuition behind this and we will, it will be more than sufficient for this course ok, that is more important here. So, effectively the gate now has to do lesser work in order to invert the channel. And therefore, the threshold voltage also will come down; which means, now the channel length has come down, the threshold voltage also has come down. And is now a function of what, the drain potential.

Earlier you remember that neither the drain current in saturation region nor the threshold voltage was a function of the drain potential. But now that is going to happen and therefore, we have to incorporate all these effects into our short channel device, correct any questions here.

So, basically what I am saying is that, I will maybe draw this a little bigger here, so that it is clearer, right. I am going to draw the short channel device now a little exaggerated. So, this is my N plus, this is my N plus again, right. Now I have my metal sorry oxide; source is grounded, body also is grounded for my experiment here, gate potential and drain potential. V D is connected to N plus, this is P ok. Body is connected to ground; which means that, that is actually a reverse bias P N junction.

So, if I increase V D then; so first of all at V D equal to 0, you will have a depletion region here around this N plus ok. Forget about the depletion region in the N plus region, that is not our concern, we are worried about what happens in the channel. So, you will have the same distance here also. Now I am going to increase it and make V D equal to V D D. So, this depletion region will now go up, because it is a higher reverse bias and therefore, you will have this region going all the way here. Now what does this depletion region mean; it means that because this is P type, it is given away a whole the immobile acceptor atom has become negative or positive; negative is given away whole, right. So, you have negative charges here.

Previously when V D was 0, my gate had to invert the entire channel from here to here, this was the channel length that the gate had to invert; which means, the threshold voltage is going to be defined by how much work it has to do to invert that much of the channel, right.

But now after my V D has increased, it is come down to this length L minus delta L prime; because of this applied reverse bias. So, now, the gate has to invert only so many dopant atoms. And therefore, part of the channel has already been depleted by the applied positive drain voltage; thereby reducing the threshold voltage. Of course, now because the two depletion region have come very close to each other; the effective channel length also has come down by a small fraction. So, there is an increase in current by two methods; delta L is reduced, threshold voltage is also reduced, ok. So, this is just the intuition for short channel effects.

Now, we will incorporate all of this into our expressions as well, ok. Did that answer your question? So, what happens is; previously when we derived the equation, all we did was to ensure that the electron had to basically go through this region reach up to here. It had to go from source to drain right, that was the net L. But now remember that in the depletion region the electric field is so high that, once it gets there it will get to the other side very easily. So, you are effectively trying to accelerate the electron only in this channel region, yeah.

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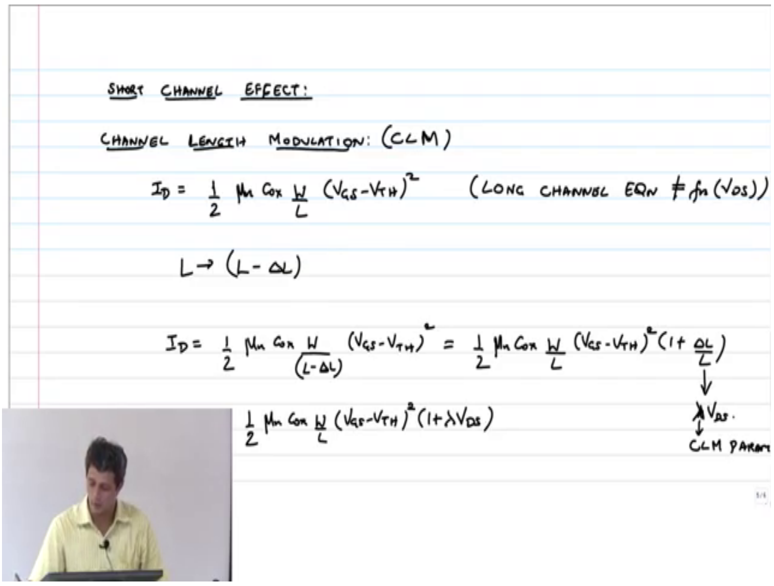

So, in the given time, I think I can derive one thing which is basically the we can derive the first short channel effect ok; which is basically channel length modulation, it is called CLM. So, we will take this expression for drain current, ok.

So, first question, will this be more severe when V D is small or when V D is very large? V D is very large. So, therefore, this will affect the saturation current or linear current? So, it is going to affect only the saturation current. So, that is a reasonable assumption to make, ok. So, you look at the saturation current, it is half mu n C o x W by L to V G S minus V T H whole square ok; long this is the long channel equation ok. And it is not a function of V D S that is the main thing. So, now, what is happening; the effective channel length is becoming smaller, it is becoming L minus delta L. And what is this L minus delta L a function of? What is delta L determined by? The V D S. Now again we resort back to our empirical modeling, we do not worry about what happens exactly physically; we say that this delta L is approximately linear with V D S, it is a fitting parameter.

If V D S goes up delta L should, it is L minus delta L. So, delta L should go up. So, lambda again is going to be a positive quantity. So, I will now replace my I D as half mu n C o x W by L minus delta L right and in fact, I will correct this a little bit more accurately now V G S minus V T H the whole square ok. So, I will do binomial approximation on the new on the denominator, remove L out 1 by 1 minus delta L by L, I will write it as 1 plus delta L by L, right. So, this will become half mu n C o x W by L into V G S minus V T H the whole square into 1 plus delta L by L. So, this is what we are going to say is lambda V D S ok, not just the delta L.

So, let me remove this to avoid any confusion ok. This lambda is called the CLM parameter, channel length modulation parameter; therefore, this will become, I D will become half mu n C ox W by L V G S minus V T whole square into 1 plus lambda V D S, ok.

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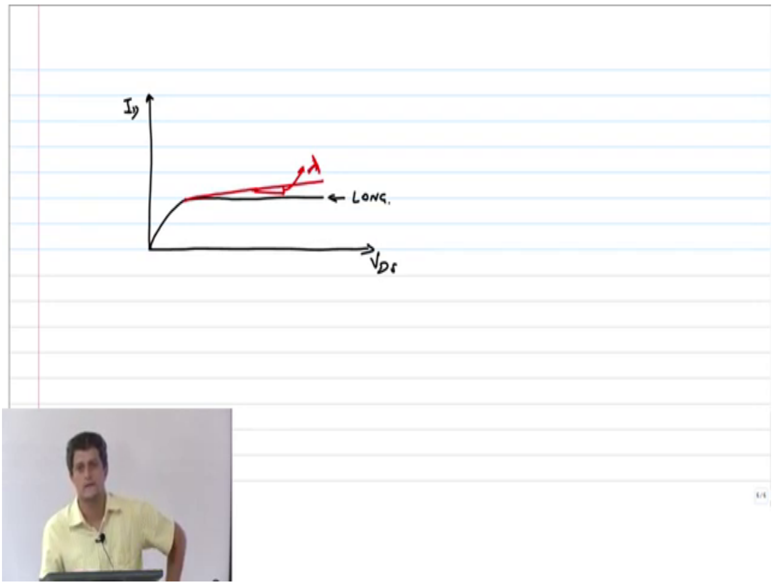

So, what does this mean in terms of the I D, V D S equation that we are talking about; I will consider the same V G S for a long channel device whose W by L is the same as that of the short channel device. So, if L is 1 micron and W is 2 micron then I will consider L to be 100 nanometer and W to be 200 nanometer, the W by L should be the same, right and V G S is also the same that is what we are assuming. So, I D versus V D S the current was basically like this, right, this is long channel.

What will happen to short channel? It will start, it will go up slightly as V D S goes up; because now that depletion region is going further into the channel therefore, you have delta L, therefore you have more current, ok. So, therefore, this current will actually go like this; remember it is not like some huge slope, it is a very small slope that you will get there, ok. This slope is basically; let me just redraw that nicely, this slope is basically lambda, ok.