Fundamentals of Semiconductor Devices
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Lecture – 34
MOSFET – An introduction

Welcome back. So, if you recall in the last lecture, we had concluded MOS capacitor. We have discussed the expression for threshold voltage and I told you in a real capacitor, there will be oxide charges that will play role. And the threshold voltage will also be affected by the flat band voltage, if there is a difference in the work-function between the metal and the semiconductor.

So, we told that from today we shall start MOS transistor - MOSFET that is field effect transistor. Field effect transistor builds on the basic premise of an MOS capacitor, except that now we shall have a source and a drain, it is a three-terminal device. And unlike MOS capacitor, which is a two-terminal device, this is a three-terminal device, so it will be a little bit more involved.

And a transistor is an active device, which means it can have gain. And we have to understand various aspects of this MOS transistor and we will always recall the expressions and the equations that we had used in MOS capacitor, because those will be used in deriving many of the expressions in MOS transistor also, ok. Please be remember, please remember that silicon MOS transistors are the most widely used transistors in your, you know, integrated chips, processors, memory logic and so on. There are different variations of MOSFETs. And nowadays, you have very highly skilled 3D versions of MOSFET, but nevertheless the basic MOS transistor, we should definitely be familiar in order to understand all the how the modern electronic gadgets work ok.

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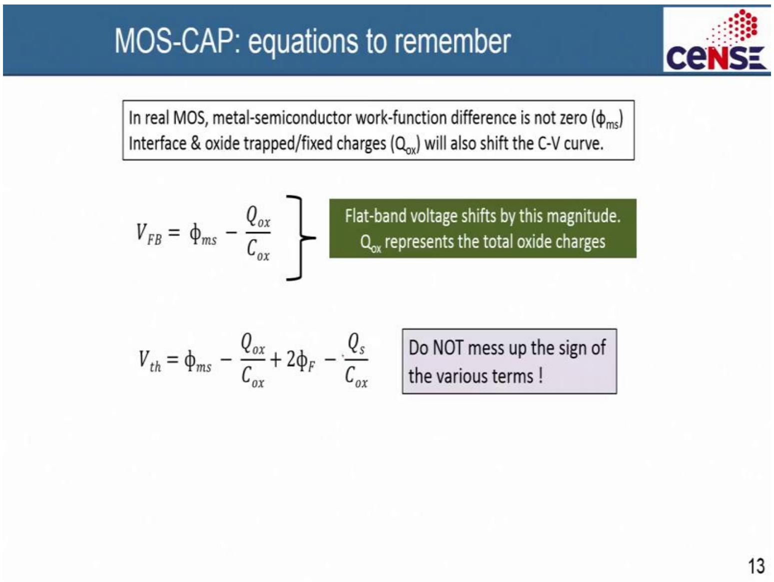

So, let us come back to the last slide that we had left. If you recall, let me take laser pointer here. If you recall, this slide had shown you the final equations regarding MOS capacitor, we have to start from here. So, if you recall, this is the metal-semiconductor work-function difference, this is the contribution from the oxide charges - fixed oxide and trap charges, so this entire quantity essentially represents the amount of voltage by which your flat band voltages shifted. Remember ideally your flat band voltage is 0, if the metal and semiconductor work-functions are balanced and there are no interface charges.

So, this quantity of flat band voltage, you have to apply to essentially, this quantity you have to apply this, whatever is voltage comes out to be, you can do a calculation and find out, it may be - 0.5 volt, it may be + 0.5 volt anything, you know that amount of voltage, you have to apply to the gate of an MOS capacitor to make the bands flat, ok.

And this flat band voltage has to be added to this particular expression, this one, you see here this particular expression over here, that is the ideal expression for threshold voltage. When you apply some gate voltage, this is a gate voltage at the threshold of course. When we apply some gate voltage, part of it falls on the oxide that is what it meant means, and part of it falls on the semiconductor, that is what it means. In inversion, in strong inversion, the band bending, or the voltage dropped in the semiconductor will be 2 times φ_F. φ_F is basically your difference between the intrinsic and Fermi level and the Fermi level ok.

So, you will basically have this expression as the fundamental expression or the ideal expression for threshold voltage. To that, you add this particular voltage, flat band voltage, you get the total net expression for threshold voltage for turning on the channel of an MOS capacitor ok. And do not mess up the signs of these expressions, for example Q_s represents the charge told in the capacitor, in the semiconductor.

Because, we if we talk about a p-type substrate, then this is the depletion charge and the depletion of p-type forms negatively charged acceptor ions. So, this will be negative for a p substrate MOS. A p substrate MOS gives you n-channel transistor n-channel MOS capacitor, because you invert the channel, which means if you have an n-channel device.

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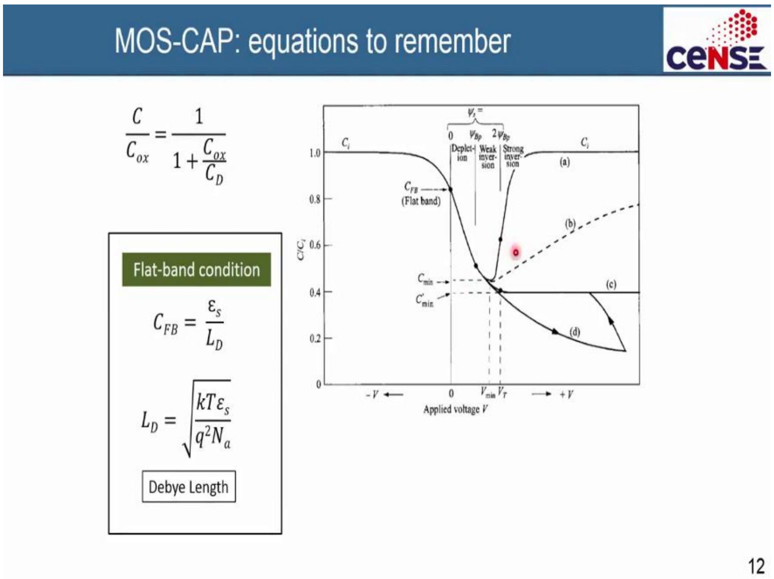

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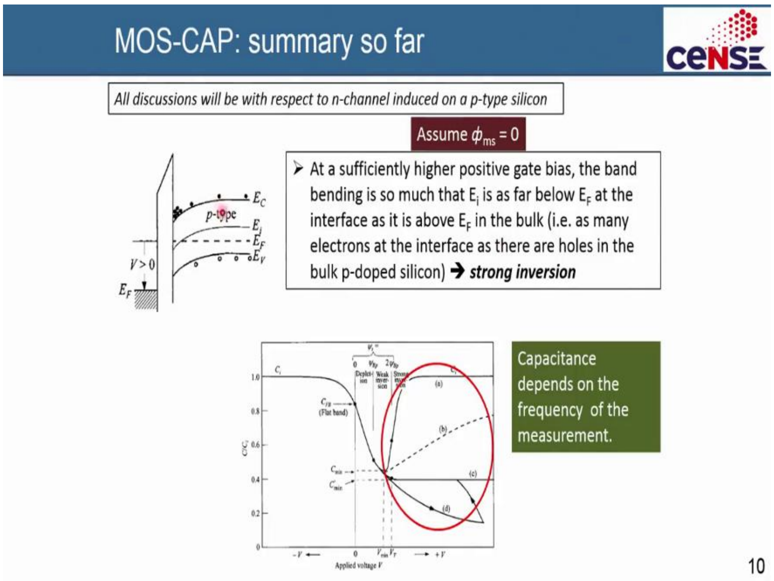

Like you know the n-channel device that, this is an n-channel device we are talking about which is a p-types substrate, this is a p-type substrates, electrons are formed here, so n-channel on a p-type substrate. In this kind of case, the depletion charge that is here is basically negatively charged acceptor ions, which means this expression that we have here. Let me come back here, this expression that we come here is actually negatively charged. And this negative sign will basically make sure that this entire quantity becomes positive, because minus, minus of something right.

So, let us not you know mess up the charge, the signs of the expressions and the terms like this is a positive oxide charges, typical it is a positive oxide charge. So, this negative will remain negative ok, so let us keep that in mind. So, this is all about your MOS capacitor, you might also recall that we had gone through other expressions of Debye length and all and let us not go back there again.

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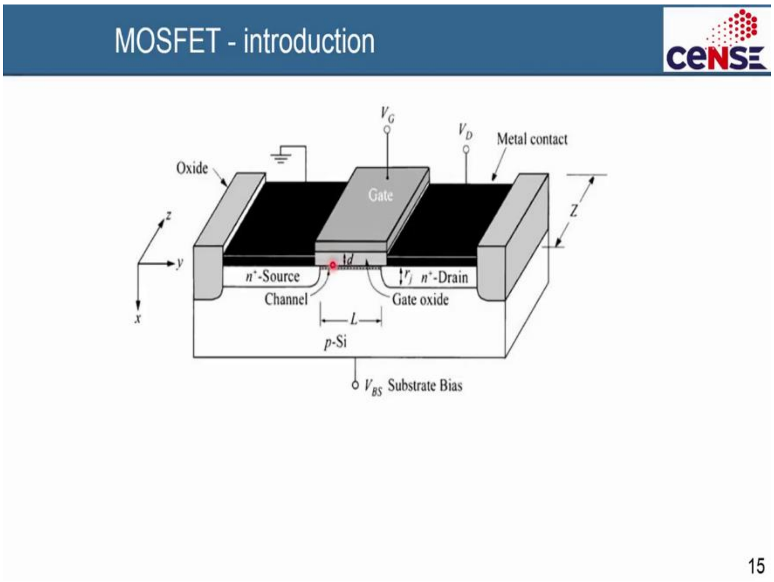

Now, we will come to transistor and you know how a basic transistor looks like. A basic transistor actually in MOS capacitor, in MOS transistor looks like this. So, let us take a minute and understand what is basically means, this part is actually an MOS capacitor. If you recall look at this part, this is an MOS capacitor, you have a gate oxide here, the d you see, is exactly the gate oxide that we have talked about, this is the gate, there is a channel that is formed.

So, this part is essentially whatever we have learned in the last few lectures, this is the MOS capacitor. Except that on the left side, now there is an n plus region, n plus very highly doped region. On the right side also, you have an n plus highly doped region. And these regions will slightly overlap with the gate you see, below the gate they slightly overlap. So, there is a continuity here you know in a way. So, this is called source, and this is called drain. This is channel that is formed, which is basically the inversion channel that we have learned till now.

And this is the oxide, this is the dielectric there. So, do not worry about, thus everything looks same, except that now, do not worry about this oxide ok, this is the oxide that is this isolation sort of a thing, we will not worry about that. You see this is a metal contact on this source, of course, gate also has a metal or a polysilicon whatever and source again drain also has a metal this black colored here.

So, this is an n plus very highly doped pocket like a source and this is also n plus doped highly doped pocket like a drain. And this is p substrate and the channel is inverting here was as soon as the channel inverts here, when you apply a strong positive gate voltage, your channel forms here as we have discussed in the last few lecture in the MOS capacitor. This channel, this channel will form here because of strong inversion, if you recall.

Now, this is n plus, this is a high-density electron, this is again n plus. So, you see from here to here, you have a path, n plus source can talk to n plus drain that means, there will be a very high current that goes through this channel of high-density electrons that is forming here ok. For the current to flow here now, you need a field a drift; a drift sort of a equation or a drift kind of a transport such that the electric field will drive this high density of inversion charge that has formed here that has to be driven from this point to that point. So, electrons have to flow, so currents have to come out.

So, what you do is that, this source you ground, which means you apply a 0 potential, you apply ground. And on the drain, you can apply a higher voltage like + 2 volt, + 5 volt, + 10 volt whatever right; so that when you apply a voltage difference between this point drain say + 5 volt and I ground, this is 0 volt.

So, in between them there is this channel that is a high-density electron that is formed because your gate is now biased at threshold voltage or more, ok. So that means they because of the field it is a + 5 volt or maybe + 3 volt, this is 0 volt. So, there is a field between source and drain that will lead to a drift sort of an equation or the transport of this electrons that will try to flow from the source.

This is like an infinite reservoir of electron, because you have lot if connecting it to the ground, you have completing the circuit, your electrons will try to flow, so that you get a current across this channel here. You will get a current across the channel here; electrons will come out from here, which means current actually is going in here that is the convention.

And of course, if you apply a little lower gate voltage that is a voltage that is lower than the threshold voltage, then this channel will not turn on, it may be in weak inversion or it may be in depletion, if you remember. And then if the channel does not turn on, then the source and drain cannot talk to each other, I mean they cannot have current between them, which is what I mean, because this channel has vanished, which means you can turn off this channel. You can turn off this channel by applying a gate voltage, which is lower than threshold voltage.

In that case, the current between source and drain will be 0, almost very low. Even though, you apply any arbitrary gate voltage drain voltage here, this is called drain voltage, this is source voltage right, this is the 0, this may be at 5 volt. If your gate is lower than threshold voltage, which means your channel is turned off, then no matter how much voltage you apply here, your current between source and drain will be negligibly small. You might apply 5 volt, 10 volt, 20 volt here, but source and drain will be basically an open circuit, there is no channel between them.

So, the gate is basically controlling, ok. This third terminal over here is controlling the current flow between this first and the second terminal. In other words, the voltage difference between this first and the second terminal, between source and drain, the voltage difference between them and them is actually not playing a role in the current, it is rather the third terminal which is able, which has this ability to transistor, to make the transistor channel vanish or come back.

If you apply a gate voltage higher than the threshold voltage, then the channel will come back, the strong inversion will occur, and the channel will come back. And you will have a current between the source and drain. The moment you turn off the channel by applying a lower gate voltage, you know then the channel vanishes and source and drain current also vanishes.

So that is why this is called a transistor, where the voltage difference between two point is not able to control the current so much. It is basically the third terminal which is able to control the current between the two terminals, that is why it is called a three-terminal device. The third terminal is the mega terminal, the main important terminal, which controls the current here and it is called a transistor ok.

Now, of course there is a lot of physics behind it, lot of equation will come you see, because the source is 0, the drain is at some finite voltage like + 5 volt, + 10 volt or whatever. So, along this channel, the potential will vary along this direction. Suppose, this I call the y-direction, this is say, this is y-direction. So, the potential will vary along the y-direction, because this is a high voltage, this is 0.

But, recall in our the MOS capacitor, we did not consider this direction, this direction y was not important to us. This z also is one important, basically this is the width of the device or the periphery of the device, you can always normalize the current or whatever with the periphery. So, this is not an important factor.

If you recall in our MOS capacitor, I will again quickly show you a figure of an MOS capacitor. You see this is an MOS capacitor in this case. All this band bending there is happening, this is happening in this direction, the direction perpendicular to the gate oxide and metal ok. It is happening in this direction the band bending, the inversion formation, the depletion formation, all this equation, all this band diagrams are in this direction, please remember in this direction, the direction which I am moving the laser pointer here. This direction is basically the direction perpendicular to the interface of this semiconductor and oxide or oxide and a metal and so on ok. We do not care about the direction.

In the direction that is entering the plane of this slide ok, not in this direction. So, what I mean is that if you come back to this MOS transistor diagram sort of things that I was showing you, ok, the MOS diagram this diagram for example, so this is the direction which is perpendicular to the metal-semiconductor interface, I mean the oxide semiconductor interface, the metal oxide interface.

This is the diagram, look at the laser pointer direction. This is the direct direction which is the x-direction, this is direction in which the band was bending, because the gate and the substrate was, you know, we are biasing this in this direction. So, the band bending, the inversion, the depletion, everything was happening in this direction. But, now there is an additional y-direction which is because this is at 0 potential, this is at maybe + 5, + 10 whatever right. So, there is because of this difference in the potential that along this y-direction, the potential will keep changing, the potential will keep changing.

So, basically this whole picture becomes a two-dimensional in a landscape, where you have y-direction along which the potential changes, because of the drain bias, an x-direction because you are applying a voltage on the gate. This is the direction in which our MOS capacitance analysis was done. So, we have the two-dimensional picture which is not very easy to solve. So, we will do some approximations and assumptions to make it simplified into one dimension that is the thing.

Now, you understand the basic working of an MOS transistor, how this terminal is able to control the current between the source and the drain, is able to control the current between the source and the drain. And this is a transistor, it can act like a switch in a way that by either taking this gate voltage higher and lower than threshold voltage, you can actually switch the channel on and off, the current between this point and this point will not depend on the voltage between this point and this point, but rather on this voltage. So, it is like a switch which you use it and you can use it all the digital logic that you do, all the NAND, NOR gates that enable you to have the digital hardware. And electronics it actually the NAND gate, NOT gate, everything works like a, in a, it’s a logic gate I mean, it is a switch sort of a thing, because the either you have a 0 or a 1 that depends on either the channel is on or off respectively.

And then you have a gate voltage that you apply that will control essentially, whether the state that you are looking at is 0 or 1, ok. So, this is the many lot of applications, you can also have a design of the transistor such that if you apply a small signal of an RF here, you might get a very amplified signal here, in which case it will be like an RF amplifier.

In some cases, it can be like a power switch, where you either have to block a very large voltage and conduct very high current. So, these are many kinds of applications of the MOSFET depends on design and many of the other aspects, but basic operation is the same everywhere. So, we will first look at although we have understood, how the MOSFET works, we also look at the basic I-V characteristics. The current voltage characteristics of a MOSFET, how do they look, ok, how do they look?

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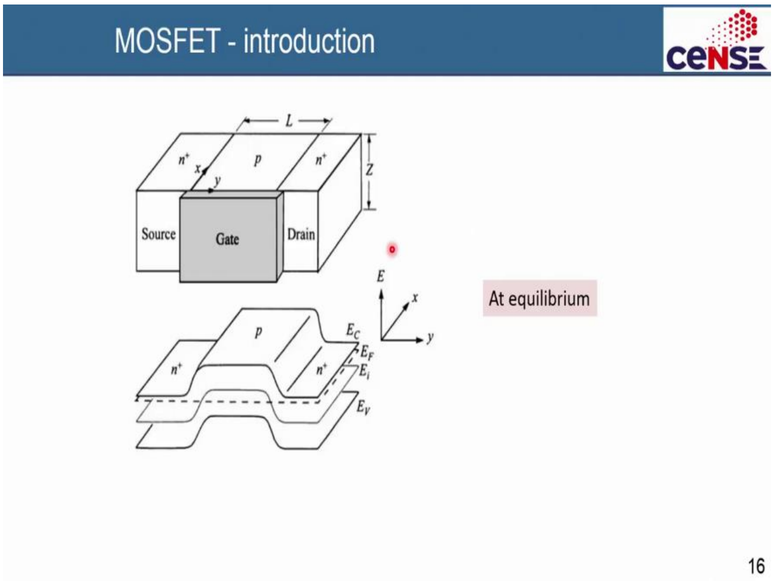

Now, we have to look we have to stop back, and we will we will pause and look at that very carefully. But, before that of course, you have to look at this particular band diagram that I am drawing you, drawing to you drawing to you in a three-dimension actually, if you have to very careful here. So, you look this is basically the transistor that we had looked here, except that I am flipping it perpendicularly. So, this is the source, this is the drain, which is the source and the drain.

So, remember this is the depth of the structure, this is the direction, the x direction in which the band bending was occurring in our MOS capacitor studies. So, this is the x-direction, remember, this is the x-direction. So, your band bending will happen in this direction, this is the x-direction, please remember this is the x-direction.

So, a band bending will happen in this direction which means, if you are applying a gate voltage which is more than the threshold voltage, then your bands will band here, not here. This is a far away from the interface between this is the gate, dielectric semiconductor interface, the in the inversion charge will happen here, not over there, not over here, it will be here.

And the moment you apply a positive voltage on the drain with respect to the source, this band along this direction, along the y-direction, it is along the y-direction it will bend. Along the y-direction it will bend, but then also along the x-direction, it will bend because of this gate voltage which induces the channel.

If the gate voltage as I told you is lower than the threshold voltage such that the channel is not formed here, then even if you apply a higher drain voltage and even if your band diagram bends like this, you will actually not get a current, because your channel inversion has not yet happened ok. If your gate voltage is lower than the threshold voltage.

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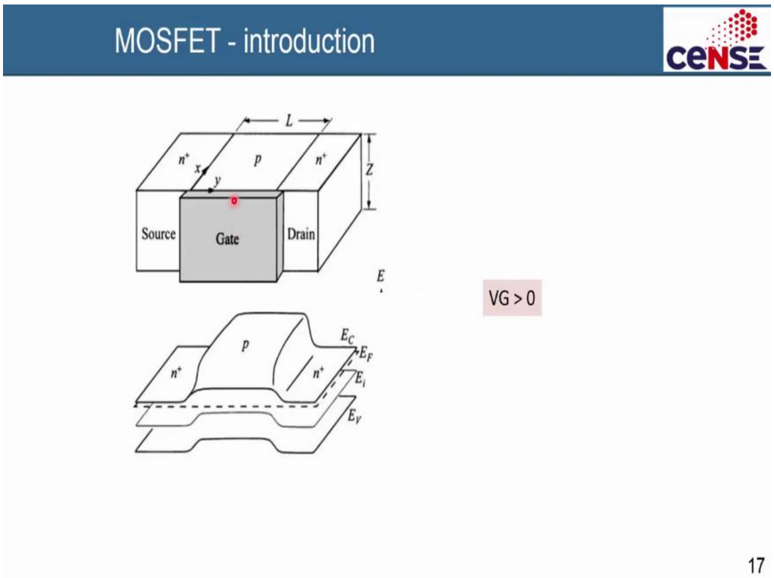

So, this is a condition that this condition was an equilibrium condition, where the gate voltage, drain voltage, source voltage everything was a 0. Now, I will apply small gate voltage, so that I want to bend and form a small channel over here, so which you see this is the small channel that is forming here.

You see the difference from here to here, its bending, its bending and there is a formation of a channel here, this is source, this is drain. And they are both are 0 0. So, there cannot be any current between them, because it is 0 and 0. There is no field here ok, there is no field here. So, nothing will push them up, the inversion that has happened here will lead to some electrons at this interface that is exactly like the MOS capacitor that we have studied till now except that now we will have a difference here, we will apply voltage here.

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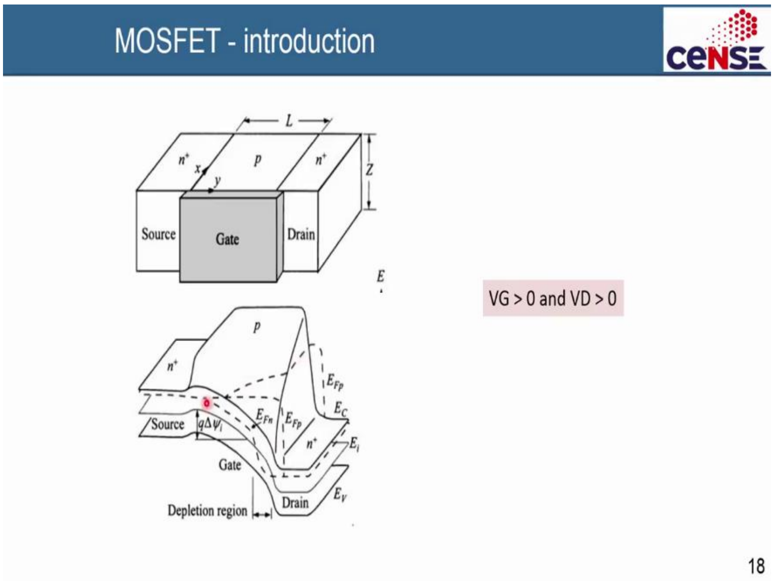

The moment you apply voltage on a drain side, drain will bend. You see the drain is bending now because you are applying a voltage here. And this total bend that has happened from the source side to the drain side, the total band bending this is happened is actually given by the drain voltage that you are applying. So, this entire bend that is happened, the amount of this bend is essentially equal to the voltage at the drain that you are applying with respect to the source.

So, you know there is different Fermi levels and quasi Fermi levels that are shown, you do not have to worry so much. Essentially, there is a channel that is formed at this interface; at this interface, you have a channel, that interface is here, that channel will basically now conduct current because the source and the drain are at different potential. So, electrons will be fed here, they will come back down here and get collected it here.

The moment you turn off the channel, it will go back to something, you know, this is not the channel turning off, this is the drain voltage being 0. But, even if you turn off the channel, the inversion will vanish here. Even if this voltage difference exists, you will not be able to get a current ok.

So, this is the condition when the gate voltage is also, you know, moving towards threshold. And also the drain voltage is higher, is good amount, so that you have band diagram like this. Now, the I-V characteristics, the current voltage characteristics of a transistor, which is the most important thing that you need to always remember.

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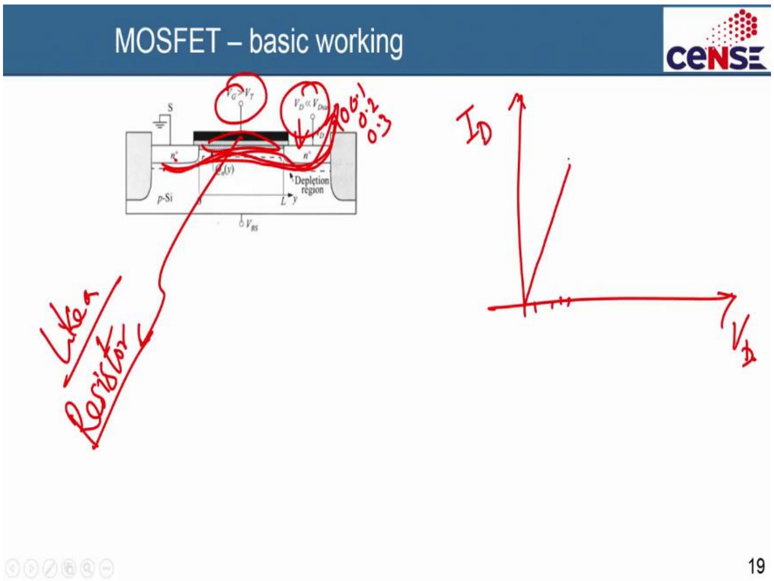

We will have to, we will come to that step by step and we will show you how the transistor characteristics look like, ok. So, first we look at the band diagram. So, takes the situation when your, you see, but remember, this is n plus pocket and this is a p-type substrate, this is n plus drain pocket, this is a p-type substrate. So, between n+ and p, there will be depletion region. The depletion region width, the depletion width is marked by this dotted, this dash lines, if you remember here. So, we can see here.

So, this depletion that has formed between the n plus source, n plus drain and the, you know, the substrate here and because this is a n+, n+, the depletion will predominantly extend towards the lightly doped p-type substrates. So, this entire depletion region is actually towards the lightly doped substrate region.

You might say this depletion I understand, this depletion I understand, why is there depletion below the gate? Well I am applying a gate voltage which is stronger than the higher than the threshold voltage, which means I have induced the channel here. I have induced a very high-density electron channel here, because the gate voltage I am applying is more than the threshold voltage. There is no point discussing gate voltage lower than threshold voltage, because there is no channel, there will be no current essentially a channel will be off.

So, I am applying a gate voltage which is slightly or maybe you know higher than threshold voltage, there is a high density of charge. And if you remember, when you apply, when you have a charge, whether you not you have an electron gas density here or not, the moment you apply gate voltage which is positive, your holes will be repelled away from here. So, you will have a depletion region here on this part also and the depletion also forms here, depletion also forms here ok. So, you will have a depletion throughout and remember this gate voltage is slightly more than the threshold voltage, now there is a channel to this formed here.

Now, the first condition is that, I apply a drain voltage here which is much lower than a voltage at which the current saturates, let us not worry about that so much now. You apply a very small drain voltage. So, between the source and the drain, there is a voltage that is applied and that is going to affect the field across this part. And we assume that the field will now go, I mean there is a linear variation of the potential across this region.

So, the current will start flowing, this will behave like a resistor and the current will start flowing ok. This will start behaving like a resistor and current will start flowing from the source and the drain slowly, because as we increase the drain voltage here, your field will increase here. And so the current, the current that is flowing across this is also going to increase as you increase drain voltage. But, remember this is all when the gate is turned on at a voltage higher than the threshold voltage. If your gate is turned off, then all these things do not matter, everything is going to be 0 ok.

So, you are applying a small drain voltage and you are slowly increasing the drain voltage. Because, this is a pure drift sort of a transport, where basically your electron holes, when electrons here of course, it will be electrons here. Electrons will experience a force, which will basically accelerate them in proportion to the field that you are applying. So, as you are increasing the drain voltage, your field here is increasing. So, your current through the channel also, it is called I_D the drain current. The drain current is the current through the channel here, the drain current also will keep increasing with drain voltage.

But, so what I mean is that, if I look at the, if I take the marker here, I mean, if I take the, so what is going to happen is that? If I am plotting the drain current; drain current is basically the current that goes here, ok, electrons that goes here actually, the electrons are going like that, so that is the drain current, the real current is coming this side, I mean that the is the notion but the electrons actually going this side, source to the channel that is formed to the drain channel is already formed, so there is no issue with that.

But, as I am increasing the drain voltage, this is called on the x axis I have drain voltage. So, I am increasing the drain voltage from 0 to then you know 0.1, 0.2, 0.3, I am increasing the voltage, your current because it is the resistor, this behaves like a resistor ok, this is behaving like a resistor, this is behaves like a resistor. So, the current will keep increasing. It will not indefinitely increase by the way, what will happen is that there is something that will very interesting it will happen, I will come to that right now ok.

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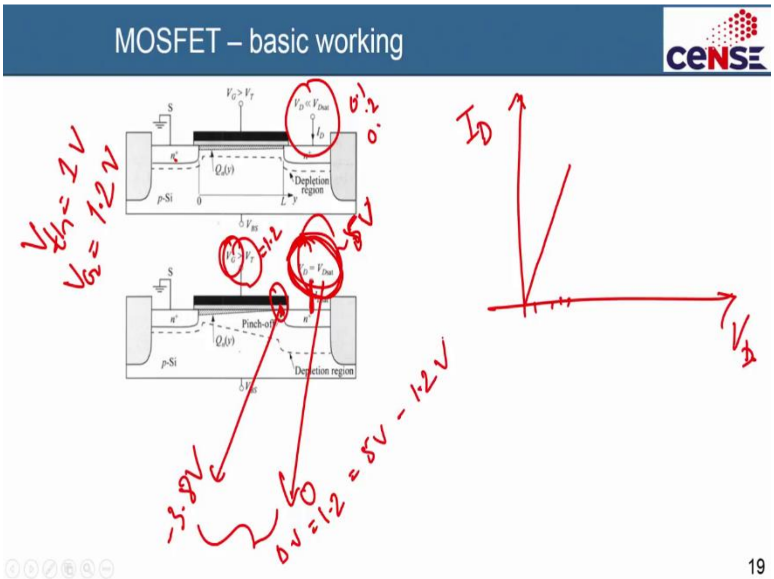

So, what will happen is that? You see when you apply a gate, when you keep applying a drain voltage which is higher and higher, what happens is that at gate you are applying some voltage, suppose the threshold voltage, suppose the threshold voltage was 1 volt, so at the gate, you are applying little higher voltage, suppose you applying 1.2 volts, so the channel is in strong inversion. So, this is 1.2 volt that you are applying on the gate, ok, here it is 1.2 volt.

But, see this drain you are applying a higher voltage say 10 volt or 5 volt or whatever. So, with respect to the drain here, with, this is a small voltage does not matter, this is a little large voltage say 5 volts, with respect to the drain here, this gate actually will be pinched off. Why? because if I take this is 5 volts, this is 1.2 volt, this is 1.2-volt, 1.2 volt, which is channel is on and this is for example 5 volt.

Instead of that, I can also say that this is at 0 volt and this is at - 3.8 volt. The difference is still, the difference the delta V is still 1.2 volt right, no this thing, the same as that the delta

V is same as 5 volts minus 1.2 volt ok, this is the same difference right. So, what I try I am trying to say is that I can say that this is at 0 volt; this is at 0 volt and the gate is at -3.8 volt which means the gate is pinched off here with respect to the drain. Why I am saying that? the same thing that essentially, I am telling you right, if you listen carefully.

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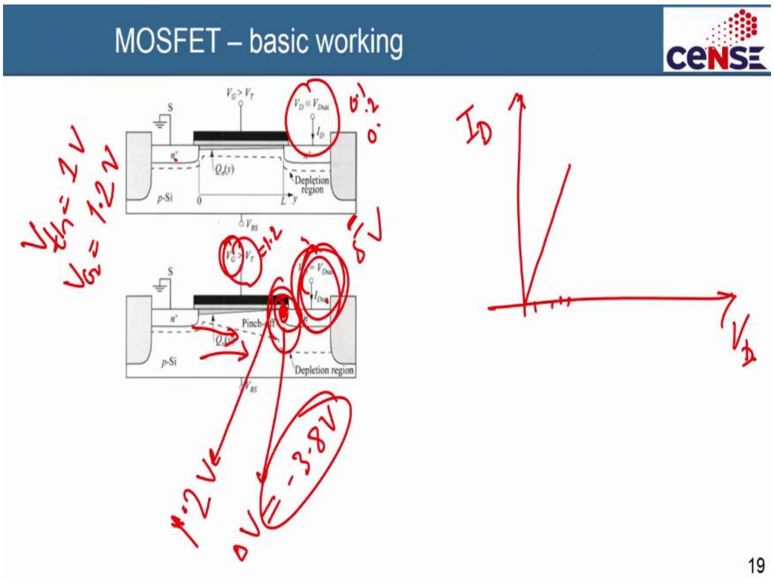

This point, if I apply at 5 volt and the gate is applied at 1.2 volt ok, it means the difference between the gate and the drain is - 3.8 volt. The delta that is there is - 3.8 volt and that - 3.8 volt is happening here, because the potential is varying linearly across this, ok. So, this point will have the extreme case, where the difference between the potential here and the potential on drain is - 3.8, which means this particular part is actually pinched off with respect to the drain; with respect to the drain, it will be pinched off, you see my point right, it will with respect to the drain it will be pinched off.

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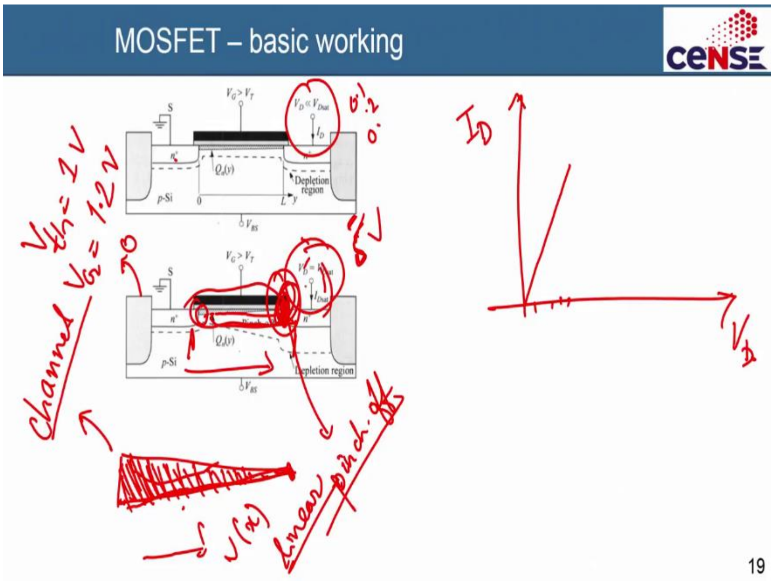

So, what will happen now; what will happen now? So, what will happen now is that this point will get pinched off, which means the channel will basically almost be not there, I mean it is it is coming to 0. And you can see this profile, this channel, this is the channel actually profile, this triangular profile that looks like this now, that looks like, this is the triangular profile.

This is actually the channel profile, this is the channel profile and this channel profile means the electrons actually. So, the electrons are highest here, electrons are gradually decreasing, decreasing, decreasing, decreasing, eventually at this point electrons will be almost 0, it is called pinch off condition. It is not a channel pinch off, it is the pinch off at the drain edge of the gate. So, this pinch off has happened.

And this gradual variation of the triangular sort of thing that means, the channel is higher here, lower, lower, lower, eventually even lower, eventually the channel becomes 0 at this point, is because the potential V(x) is linearly varying, the potential is linearly varying across from this point, to this point, the potential is linearly varying, because you are applying drain bias say some 5 volt to 10 volt or whatever and this is 0 volt.

So, the potential is linearly varying and that is why the shape of this going like that; at one point here, the difference potential between this drain and the gate is essentially such that the gate is pinched off with respect to the drain. So, the channel is pinched off at that point.

You see that point that is written very carefully over there ok, it has written very carefully over there. Let me rub out here again ok.

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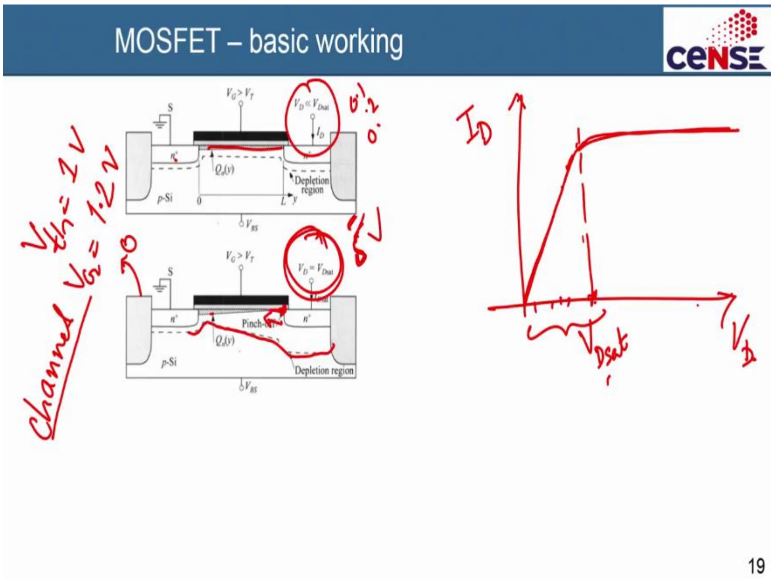

So, you see that channel is pinched off over here and the moment the channel pinched off over here, the current will not increase any further, the current will basically saturate, sort of tend to saturate. So, this point is called V_{Dsat} that means, it is the onset of saturation ok. Till this point only, you can go linearly with the resistor, this behaving like a resistor. At this point some point here, there will be pinch off here, which will prevent the current from increasing any arbitrarily further anymore.

And after this point, what will happen is that as you apply more and more drain bias beyond this point, as you apply more and more drain bias, the current will saturate like this; the current will saturate like this, why? Because as you apply more and more drain bias after that, your depletion, this is your depletion you see, this is your depletion. This depletion will increase ok, because, you are applying more positive voltage here and the depletion will increase. And this pinch off voltage will move to the left, you will deplete more, and it will move to the left.

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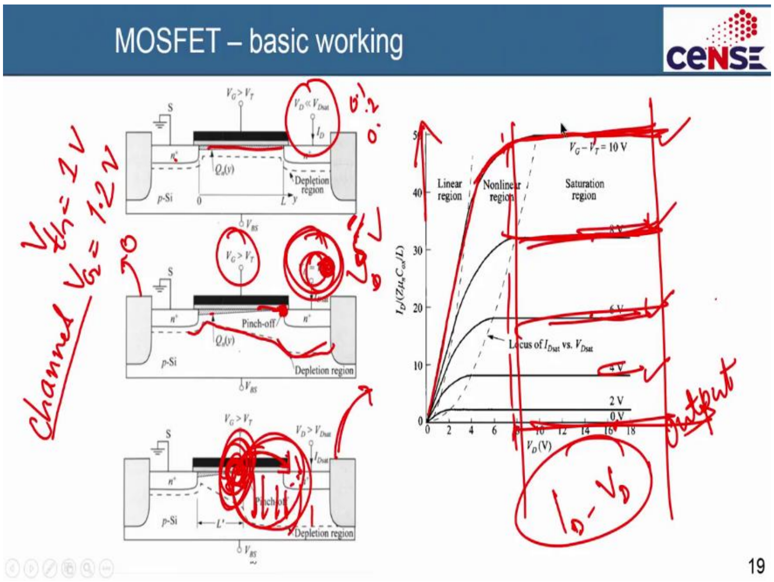

So, what I am saying is that, if you look at the next figure here, we will come to the figure over there, ok, we will come to the figure over there. And same thing I was drawing here actually, this is the same figure that has come here. This you see, this pinch off over here has now moved over to here. The pinch off has moved there, so now the depletion has also increased a lot, you see compared to this, the depletion has increased a lot. And the pinch off has come over here, because you are applying a more and more drain bias, so the pinch off keeps coming to the left ok.

And this point, and this point, this is a depleted region, and this behaves like a base collector junction of a BJT, if you recall, it is a very high field region that exist like a base collector reverse bias junction. So, whatever electrons reach here at this point, will be swept away, will be swept away by the field from this point to this point. This is a huge field here.

So, whatever electrons reach this point, ok, and this point will be such that electron density will almost go to 0, whatever electrons reach this point, will be swept away by the field, where very strong field exists here to this side ok. And that is like a base collector depletion region, reverse depletion region, if you recall is the same thing, almost the same thing ok.

So, how many electrons are arriving here matters, not what with what speed they are being swapped away by the field here; that is why, the number of electrons arriving here will be constant, because this voltage will be maintained at this voltage, this voltage ok. So, that voltage will be maintained here, even if it goes here, here, it will be maintained here, so the number of electrons arriving here is the same, it does not matter where the point is, so the current will be constant.

How fast they are swept away by this huge field here is not important, just like a base collector junction of a BJT ok. So, essentially what we are going to get is that, initially you will have a linear sort of a curve, the moment you have a pinch off here, you will, you will deviate from the linearity. And any more after that you apply, any more drain voltage you apply, your pinch off is going to move to the left, your pinch off is going to move to the left here, depletion will widen even more, depletion will widen even more, your pinch off has moved to the left and how many carriers are reaching here actually matters as to how many how much of current, you will get here.

This remember, this entire region is a very high field region like base collector junction of a BJT, it will sweep away very fast, that is why, it will be saturated there will be no, because at this point, the number of electrons reaching is constant and this and this and this correspond to different gate bias. So, your gate bias, if you keep increasing the gate bias, 2-volt, 4-volt, 6 volt and all, then you will get more and more and more and more current for the same drain voltage, seeing my point.

So, basically this is the I_D - V_D characteristics, this is called the I_D - V_D characteristics of MOSFET, which also is called output characteristics of the MOSFET, because you are looking at the output current and you are looking at the output voltage, this is the output current and this is the output voltage ok. So, this is called I_D - V_D characteristics. And you see that different gate voltage, if we increase the gate voltage, you are also channel increases. For a given, you know this particular is current is saturated, which means the drain actually does not have any influence on this part, only the gate will be able to modulate the charge ok.

So, this is the basic working of the MOSFET and what we will do is that we will wrap up our lecture here today. So, we have introduced the basic MOS transistor, I told you that, it is a 3 terminal device and we discussed about the basic working, very qualitatively no equation, no expressions have come, no Maths have come till now, they will come later.

So, we have understood the working of the MOS transistor, how it works, why the channel pinches off and why the current saturates, so that was what our class today was intended to be. What we will do in the next class is that we will take it forward, we will probably go to some of the Maths. It is very simple Maths to explain the threshold voltage, it will be very similar to MOSFET or MOS capacitor, we will derive some expression for threshold voltage, we will do some I_D - V_D you know.

And also get a little bit more in to the different other characteristics like gate, the transfer characteristics like the drain current versus the gate voltage and so on. And we will also take help of some simple equations, to derive this I_D - V_D that I showed you just now ok. Some simple equations to derive them, which will be helpful to you, that we shall, we shall do that in the next class.

Thank you.