Design of Power Electronic Converters
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Lecture 13
MOSFET

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Welcome to the course on Design of Power Electronic Converters. So, we were in the module of power semiconductor devices. In today's lecture we will be discussing MOSFETS.

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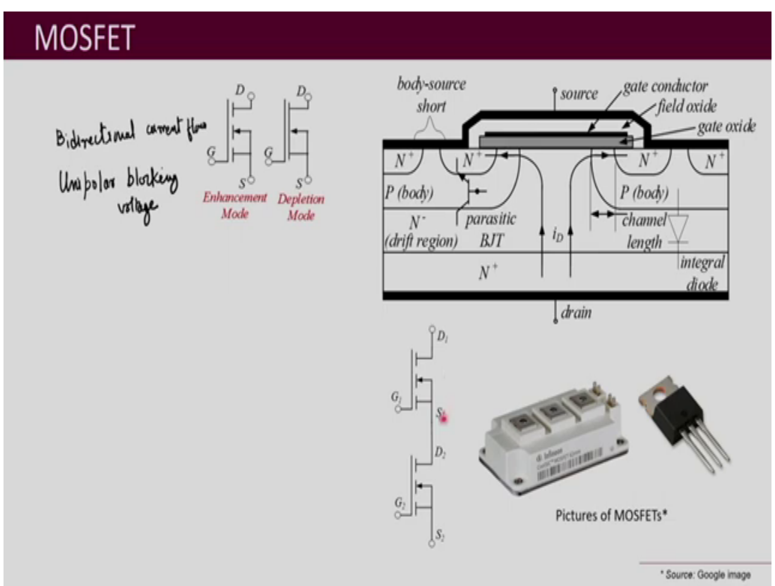

This is the physical structure of the MOSFET, this shows the basic physical structure, the structure of course varies with the type of MOSFETS. And what you see here is that, you have this N plus region, then you have the N minus region, these two actually are consisting of the drain and it gets connected to the drain. And then you have this P region and then you have the source, which is basically N plus region.

And then what you also see here is gate area, where you have these metallic conductors and then you have in between this field oxide. So, there is this oxide, so that is why it is called as the metal oxide field effect transistor.

Now, various different types of MOSFETS are there. So, the symbols also are slightly different depending on that. So, this one is the symbol of N channel depletion mode MOSFET and this is N channel enhancement mode MOSFET, the symbol of this.

Now, what I have seen is that, many times people do not cautiously use the symbol, when they are simply drawing the power electronic circuits. So, just by using at the circuit of the power electronic converter do not assume that what is the type of MOSFET that is going to be used for that converter. So, this is N channel enhancement mode MOSFET, this is the one which is mostly used for electronic converters.

Now, these are the pictures of MOSFETS, this is a discrete MOSFET, power MOSFET and you can see these three legs, three terminals coming out which are gate, drain and source. Then it may be also available in the form of integrated modules, this is a picture of integrated module by Infineon and what it contains inside is this two MOSFETS connected like this in forming one leg of an inverter. So, here main terminals are drain, the source and drain these two are connected together and then there is this source, so those are these three terminals that you see here in the module.

And then also you will be having this gate and source for one MOSFET and gate and source of another MOSFET. Apart from this, when you observe this physical structure, what you see here is that, there is a parasitic BJT inside this MOSFET. So, when you see this drain current, so mostly inside the MOSFET, when it flows it goes to the N plus N minus P and then N plus and so it flows from drain to source.

So, and that also is the direction of current that you see if this parasitic BJT turns on, so that also will be allowing the conduction of current in the same direction, plus you see here an integral diode, which is called as the body diode of the MOSFET. So, this body diode allows the flow of current in the opposite direction from source to drain, so that is why what we can say is that MOSFET allows conduction of current in both directions, it is bi-directional current flow, which is possible in MOSFET.

And that is mainly because of this body diode and it is helpful in power electronic circuits, because you do not have to connect an additional diode for opposite direction of current flow many of the power electronic circuits require the flow of current in both directions and that is where this body diode becomes useful. So, that is why you should keep it in the mind that bi-directional current flow is possible in MOSFET and that is mainly because of the body diode.

But mostly when you consider the blocking voltage, so blocking voltage is only of one polarity, unipolar blocking voltage. And this is also something that is expected by you, because if there is a diode over here, anti-parallel diode, body diode, so that will not block the voltage of opposite polarities. So, only unipolar voltage, that means the voltage where drain is positive with respect to source, those voltages can be blocked by the MOSFET. So, when you see the blocking voltage specification of a MOSFET, that is basically with respect to source, how positive the drain can be.

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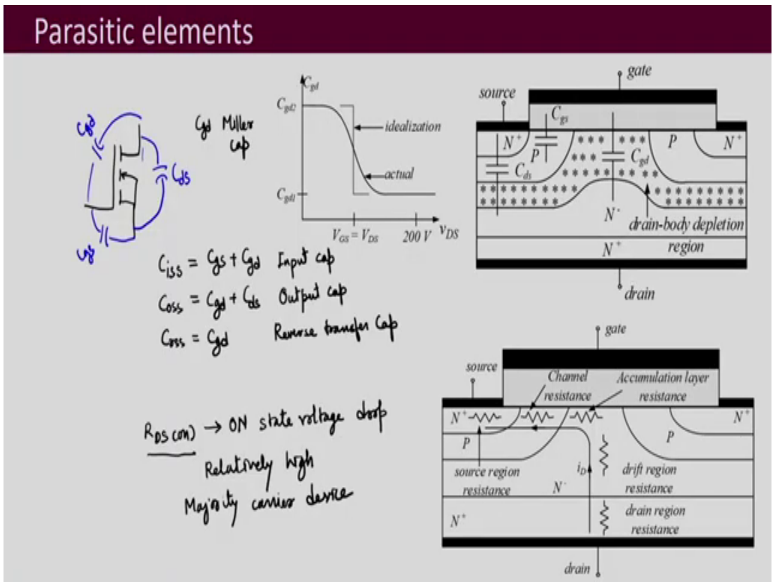

Now, let us look into more of the parasitic elements, which are present in the MOSFET. Before this I would like to tell you that there are many parasitic that are involved in MOSFETS, we are not going to discuss all of them. As I have told you before also in case of diode, we will not be going into the device physics. We will be looking only into the terms, which are important for understanding data sheets from design perspective of power electronic converters, whatever is required that is what we are going to see in this course.

So, the key parasitic elements, which play a role that is one is BJT, we saw that in antiparallel diode or the body diode that is also very important. And apart from that there are three capacitances in MOSFET, one is C_{gd} gate to drain, there is a capacitance, then between gate and source there is another capacitance and then between drain and source there is another capacitance.

So, if I draw it, so three capacitances over here, one is gate to drain, then between gate and source and then another one between drain to source. So, this C_{gd} gate to drain this is also called as miller capacitance, it actually is responsible for showing a miller effect. So, what we see here is that, that this is C_{gd} this gate to drain capacitance versus drain to source voltage.

So, when drain to source voltage is very high of the order of the rating of the diode, of the MOSFET voltage, then what you see is that, that this C_{gd} is relatively less. Then as this drain to source voltage reduces, then what we see, this gate to drain capacitance, that increases a lot and that is that miller effect that happens inside the MOSFET. And based on these three capacitances there are three capacitances mentioned in the data sheet, one is input capacitance C_{iss}.

So, this is sum of gate to source and gate to drain. So, this is input capacitance and then you have the output capacitance, which is some of C_{gd} and C_{ds}, and you have the reverse transfer capacitance, which is basically C_{gd}. So, these three capacitances, these are of lot of importance in MOSFET, because they play very important role during the turn on and turn off process of the MOSFET.

Then there is another important parasitic element, which are resistances in the MOSFET. So, here you can see that, there are different resistances associated with different regions of the physical structure of the MOSFET, N plus region has a resistance, P region has a resistance, then inside this drift region has a resistance, N plus region has a resistance. So, all these have various different resistances. So, now we can just use one resistance, which shows the effect of all of these, so that is $R_{DS(on)}$, which is associated with on state voltage drop in the MOSFET.

Now, usually this $R_{DS(on)}$ is significant and on state voltage drop for MOSFET is relatively higher as compared to BJT or IGBT. And the reason is that, MOSFET is a majority carrier device, only one type of carriers, they play role in the conduction of current through the MOSFETS and that is why these are majority carrier device.

And so, what happens is that the on state voltage drop becomes higher, it is also responsible for the MOSFET to be very fast device, it turns on and turns off very quickly, because it is a majority carrier device, but then there is a cost to it and that cost is in terms of the $R_{DS(on)}$, that increases and the on state voltage drop increases. So, conduction loss then becomes higher in MOSFET.

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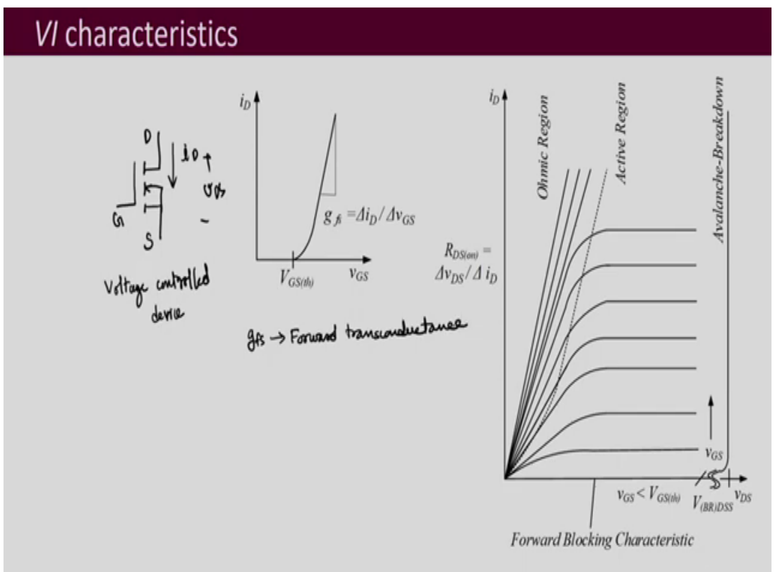

Now, let us see the VI characteristics of the MOSFET. So, this is i_D and then this is V_{DS} drain to source voltage. So, here you can see that it has got three regions, one is this Ohmic region and then you have this active region and then you have this cut off region. So, Ohmic region, what is happening is that, drain to source voltage is very small, but currents can be very high, so that is Ohmic region. And why we are calling it as Ohmic region? Because you can see here that it is almost like a straight line, it is like a resistive nature of the MOSFET, so that is why we are calling it as Ohmic region.

Then there is this active region, in this active region what you see here is that, both drain to source voltage and drain current they both can be high together. So, more losses are going to take place in this active region. And so, this region is absolutely not preferred in power electronic circuits, you have to operate it in Ohmic region or you will be operating in this cut off region, where what you can see, which is written as forward blocking characteristics over here, we see that, the current is negligible very small and the voltage it can block is very high. And after that if you exceed that voltage, then actually breakdown is going to happen.

And this $R_{DS(on)}$ is associated with the slope of these lines in Ohmic region. So,

$$R_{DS(on)} = \frac{\delta V_{DS}}{\delta i_D}$$

And then as you go from cutoff to Ohmic, how you can do that is using this gate to source voltage. So, when we increase this gate to source voltage, we have to increase it first above threshold voltage, if the gate to source voltage is below threshold voltage, what will happen is that it will be in the cut off region, it will not be conducting. After that as you increase gate to source voltage above threshold, then it will go into active region.

So, here depending on how much gate to source voltage you provide diode current is limited by that, you can see these straight-line curves, which are parallel to V_{DS} axis. Depending on what is the value of V_{GS}, i_D is getting decided. So, MOSFET if you want to use it for amplifier applications in analog electronics, then this is the region in which it is used active region.

And further if you increase gate to source voltage, then what happens? It goes into the Ohmic region. So, all these different, different curves that you see are for different, different values of gate to source voltage. So, what we observe from here is that by controlling, by changing the gate to source voltage you can control the MOSFET that means you can drive it from cut off to Ohmic region or from Ohmic region to cut off region. So, then what we understand from this is that, MOSFET is a voltage-controlled device.

Then this shows i_D versus V_{GS}, forward transfer characteristics, this is called as the output characteristics and this is called as the forward transferred characteristics, this is of i_D drain current, versus gate to source voltage V_{GS}, that is shown here and as I told you below this threshold voltage $V_{GD(threshold)}$, this MOSFET will not allow any conduction, it is in cut off. So, no i_D and then it increases as V_{GS} is increased and this is called as the forward trans conductance g_{fs}.

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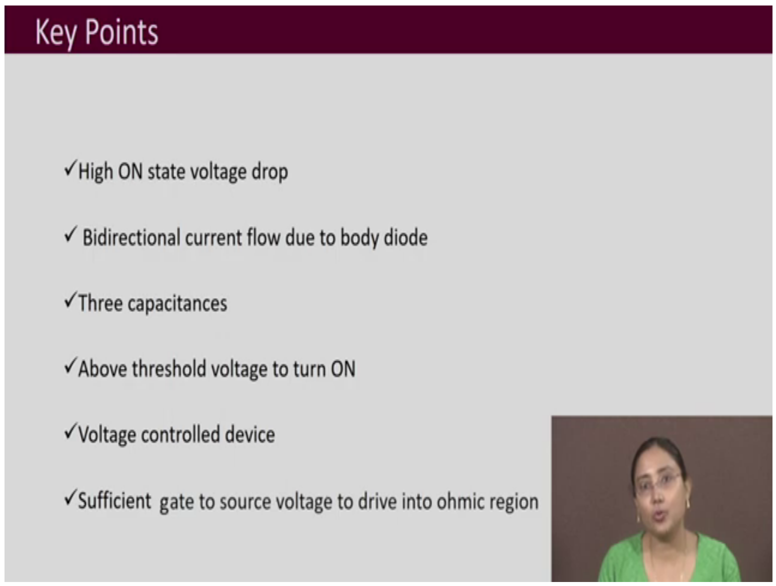

So, what are the key points of this lecture? First of all, MOSFET is the majority carrier device, so it has got high on state voltage drop. Then bi-directional current flow is possible, because of the body diode. Then there are three capacitances, which are of lot of importance for turning on and turning off of the MOSFET. And MOSFET starts to conduct when V_{GS} the gate to source voltage is above the threshold voltage and it is a voltage control device, you basically change gate to source voltage to control, that means for to go from Ohmic region to your cut off region or vice versa.

And sufficient gate to source voltage needs to be provided to drive it in the Ohmic region, when gate to source voltage is low, it is in cut off, when it increases further it goes into active region. And then when you further increase it and it is sufficiently enough the gate to source voltage, then it goes into the Ohmic region. Thank you.