METAL OXIDE SEMICONDUCTOR FIELD EFFECT TRANSISTOR (MOSFET)

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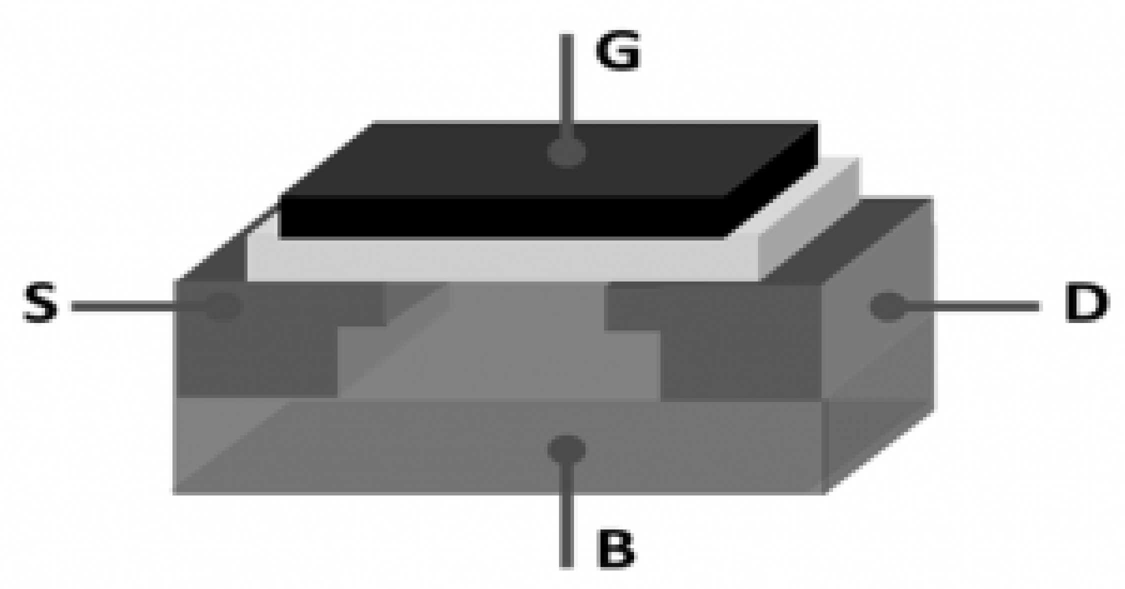
MOSFET

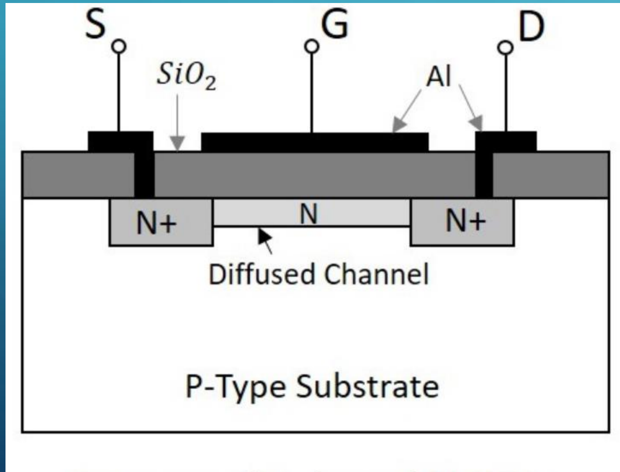
- MOSFET stands for Metal Oxide Silicon Field Effect Transistor or Metal Oxide Semiconductor Field Effect Transistor. This is also called as IGFET meaning Insulated Gate Field Effect Transistor.
- A MOSFET is a four-terminal device having source(S), gate (G), drain (D) and body (B) terminals. In general, The body of the MOSFET is in connection with the source terminal thus forming a three-terminal device such as a field-effect transistor. MOSFET is generally considered as a transistor and employed in both the analog and digital circuits. This is the basic **introduction to MOSFET**.



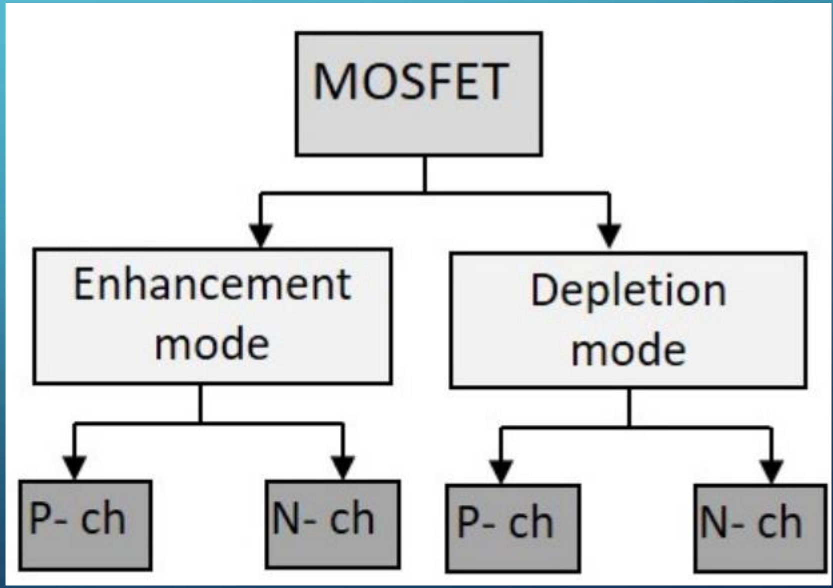
CONSTRUCTION OF MOSFET

The construction of a MOSFET is a bit similar to the FET. An oxide layer is deposited on the substrate to which the gate terminal is connected. This oxide layer acts as an insulator (sio_2 insulates from the substrate), and hence the MOSFET has another name as IGFET. In the construction of MOSFET, a lightly doped substrate, is diffused with a heavily doped region. Depending upon the channel used, they are called as **P-type** and **N-type** MOSFETs.

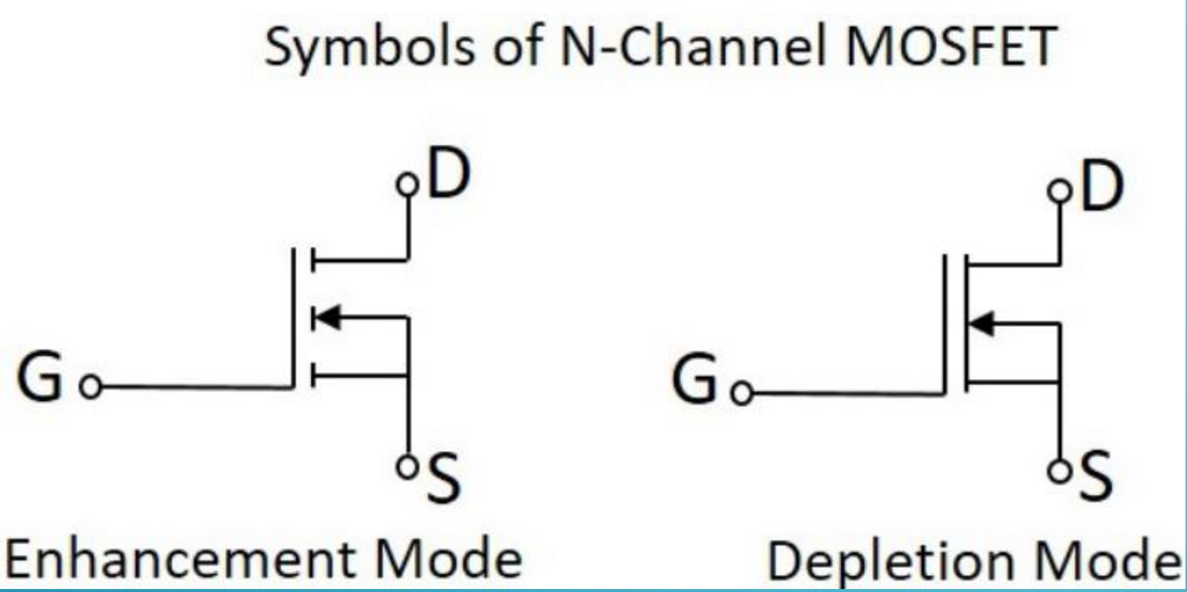
The voltage at gate controls the operation of the MOSFET. In this case, both positive and negative voltages can be applied on the gate as it is insulated from the channel. With negative gate bias voltage, it acts as **depletion MOSFET** while with positive gate bias voltage it acts as an **Enhancement MOSFET**.

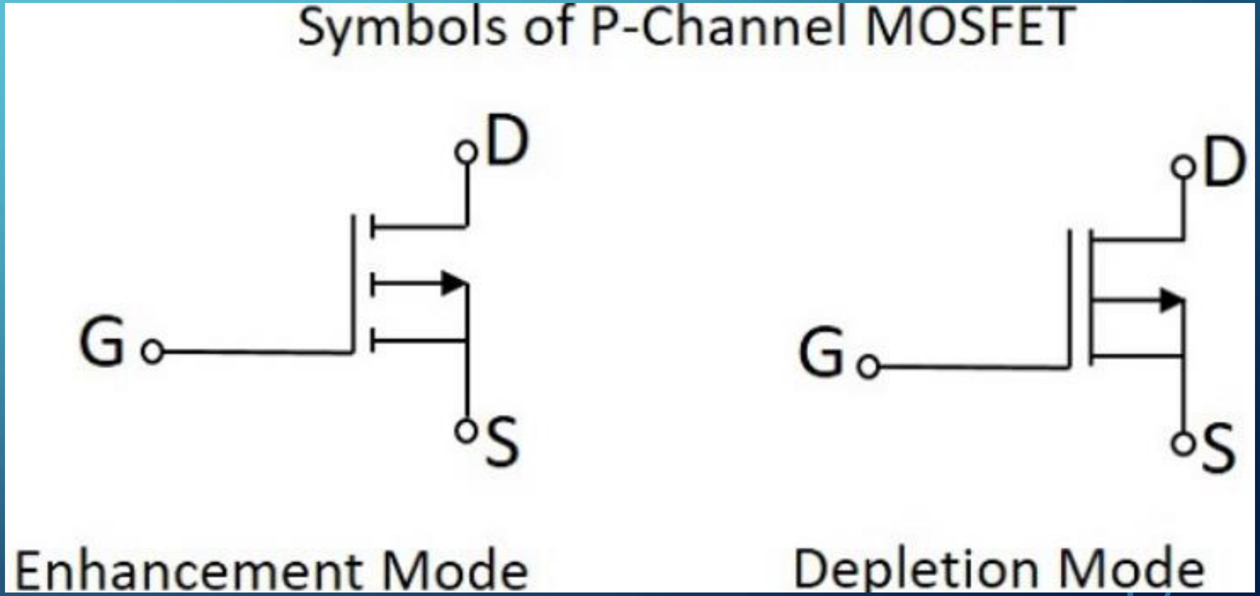


Structure of N-channel MOSFET



GRAPHICAL SYMBOL





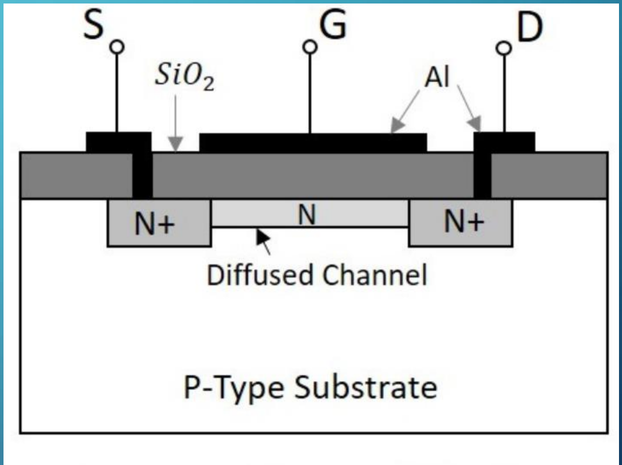
WHY GRAPHICAL SYMBOLICAL DEFFERENCE?

1. **Enhancement-mode MOSFETs**: These MOSFETs are normally off devices, meaning that they do not conduct current between the source and drain unless a voltage is applied to the gate terminal. The symbol for an enhancement-mode MOSFET typically shows no channel between the source and drain terminals, indicating that no current flows when there is no gate voltage applied. When a positive voltage is applied to the gate, it creates an electric field that attracts charge carriers (electrons for n-channel MOSFETs, holes for p-channel MOSFETs) to form a conducting channel between the source and drain, allowing current flow. The symbol usually depicts this by showing a broken line or a gap between the source and drain terminals, representing the normally non-conducting state.
2. **Depletion-mode MOSFETs**: These MOSFETs are normally on devices, meaning that they conduct current between the source and drain even when no voltage is applied to the gate terminal. The symbol for a depletion-mode MOSFET typically shows a channel between the source and drain terminals, indicating that current flows even without a gate voltage applied. When a negative voltage (for n-channel MOSFETs) or a positive voltage (for p-channel MOSFETs) is applied to the gate, it depletes the channel of charge carriers, reducing the conductivity or even turning off the device. The symbol usually depicts this by showing a solid line or a connected channel between the source and drain terminals, representing the normally conducting state.

CONSTRUCTION OF N- CHANNEL MOSFET

Let us consider an N-channel MOSFET to understand its working. A lightly doped P-type substrate is taken into which two heavily doped N-type regions are diffused, which act as source and drain. Between these two N regions, there occurs diffusion to form an N channel, connecting drain and source.

A thin layer of **Silicon dioxide (SiO_2)** is grown over the entire surface and holes are made to draw ohmic contacts for drain and source terminals. A conducting layer of **aluminum** is laid over the entire channel, upon this **SiO_2** layer from source to drain which constitutes the gate. The **SiO_2 substrate** is connected to the common or ground terminals.



Structure of N-channel MOSFET

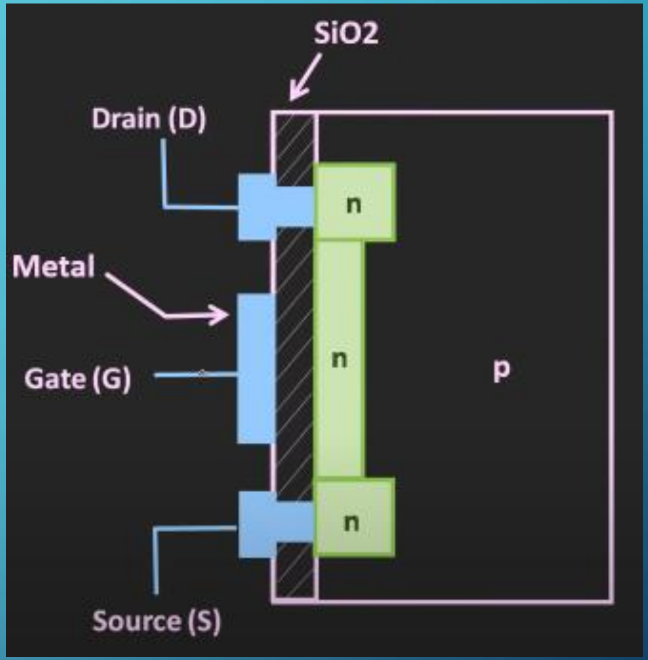
Because of its construction, the MOSFET has a very less chip area than BJT, which is 5% of the occupancy when compared to bipolar junction transistor. This device can be operated in modes. They are depletion and enhancement modes.

N- CHANNEL MOSFET

- When we apply voltage at the gate terminal then due to the electric field, it can either deplete or enhance the charge carriers in this given channel.

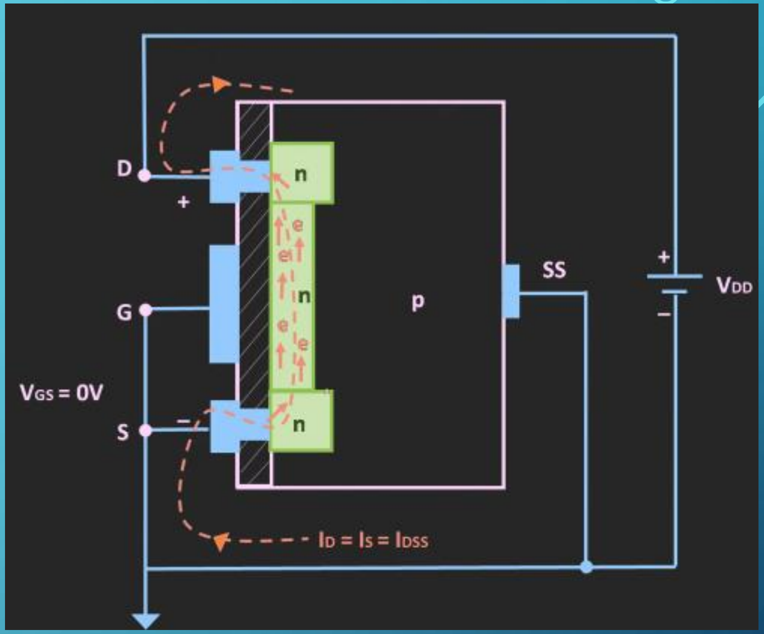
- So, by application of the voltage if the number of charge carriers gets depleted in this channel then it is known as Depletion type MOSFET.

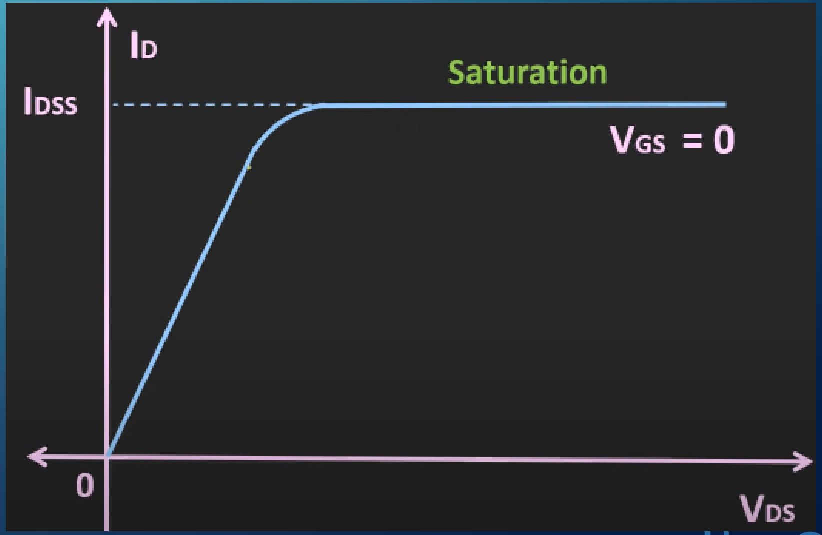
- Or if the charge carrier increases, it is known as enhancement type MOSFET



WORKING OF N- CHANNEL MOSFET

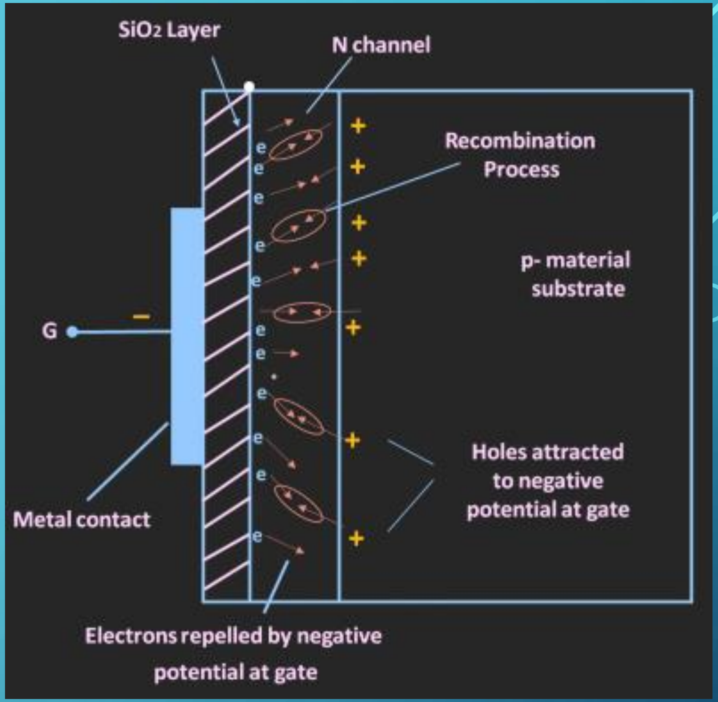
- Initially lets assume, the gate and source terminals are connected together and they are connected to the ground. Which means initially Vgs=0V
- And positive voltage, Vdd is applied between the drain and source terminal
- So, as soon as we apply the Vdd, the electrons in this channel get attracted towards the positive terminal.
- So, if you observe from the source terminal electron start
- flowing towards the drain terminal and this way current, Id will be established from the drain to source terminal
- If we increase Vdd, Id will increase and this process will continue until all the electrons in this channel contributes in the flow of current
- After this if we increase the Vdd, the current which is flowing through the channel will become constant.

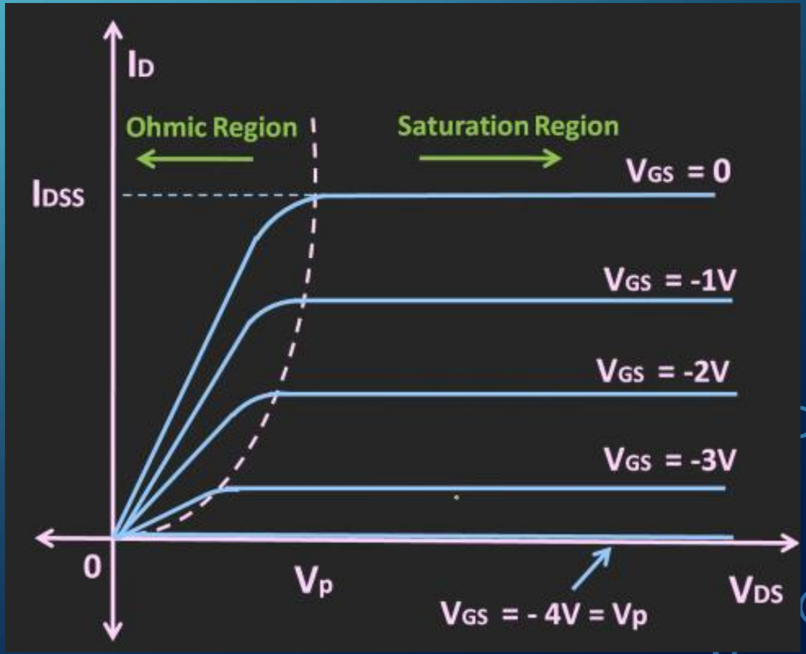




WORKING OF N- CHANNEL MOSFET

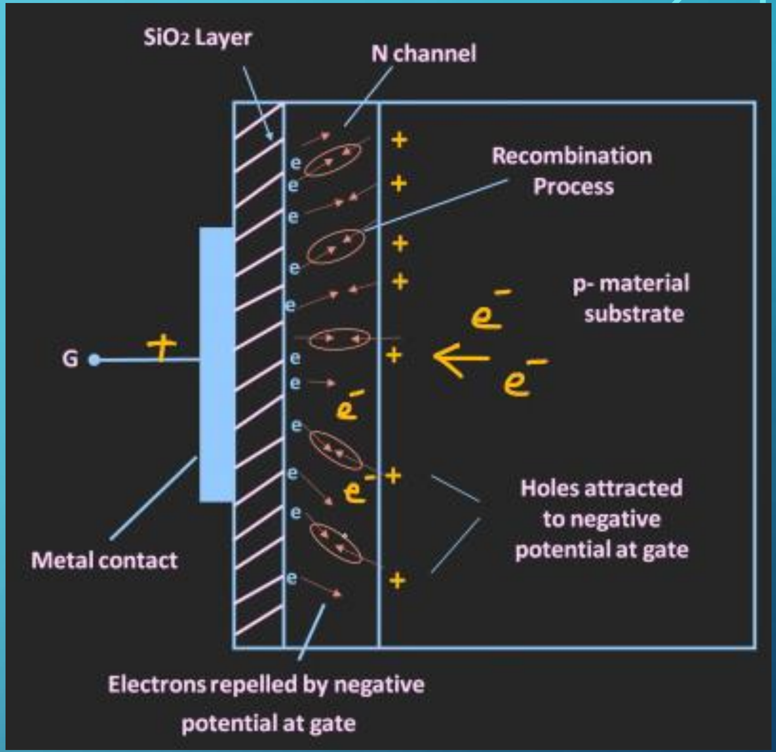
- This current is called Idss.
- When Vgs is set to negative value, the negative voltage at the gate terminal will push the electrons of the n-channel towards the p-type substrate.
- At the same time the holes in the p-type substrate will get attracted towards these electrons.
- So in short, due to the negative voltage at the gate terminal the electrons in the channel will get recombined with the holes.
- The rate of recombination will depend on the applied negative voltage
- So, as we increase the negative voltage rate of recombination will rise. That will reduce the number of free electrons available in the n- channel and effectively reduce the flow of current.

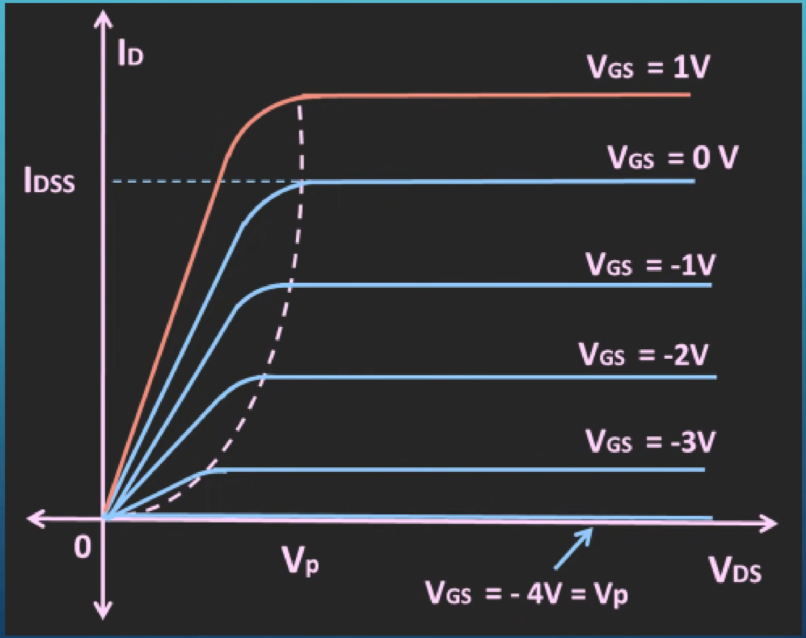




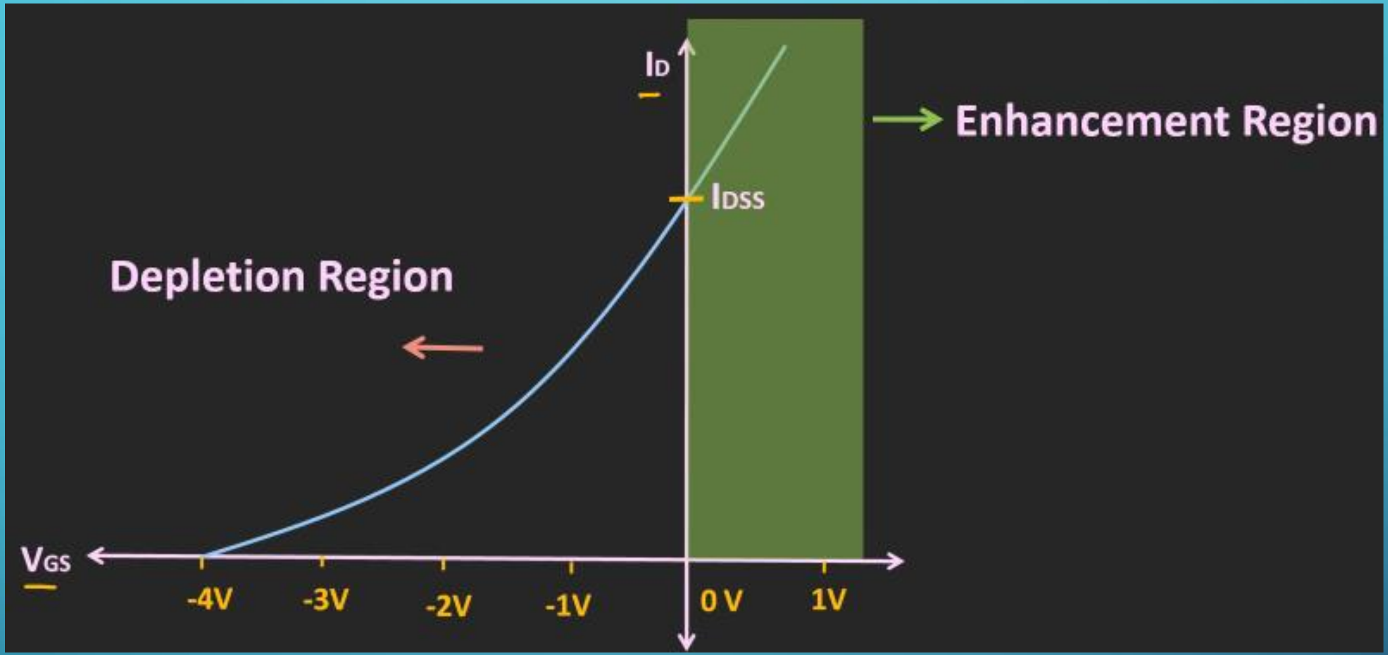
WORKING OF N- CHANNEL MOSFET

- This MOSFET also works for the positive values of Vgs.
- Whenever positive voltage is applied to the gate terminal, the minority electrons in the substrate get attracted towards this n-channel. Due to this the number of free electrons in n-channel will increase. So effectively we can say that the flow of current in this n-channel will increase.
- So for positive voltage of Vgs, the Id will even more than for Vgs=0V.



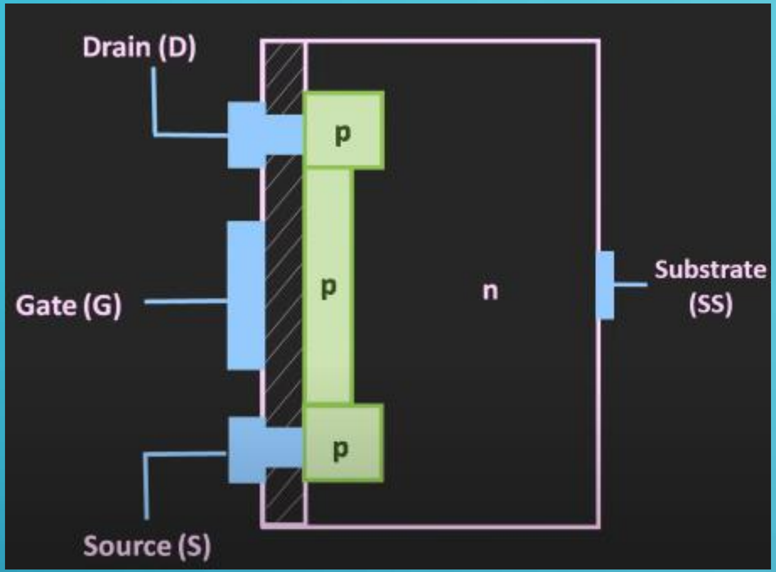


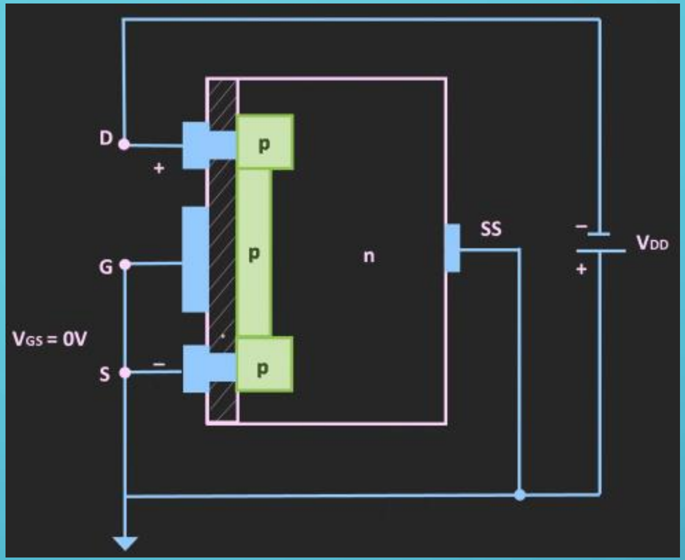
TRANSFER CHARACTERISTICS OF N-CHANNEL MOSFET

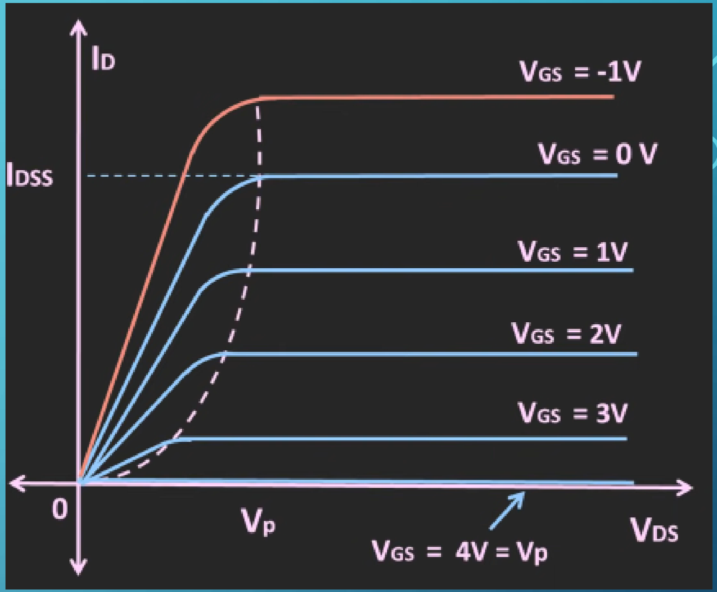


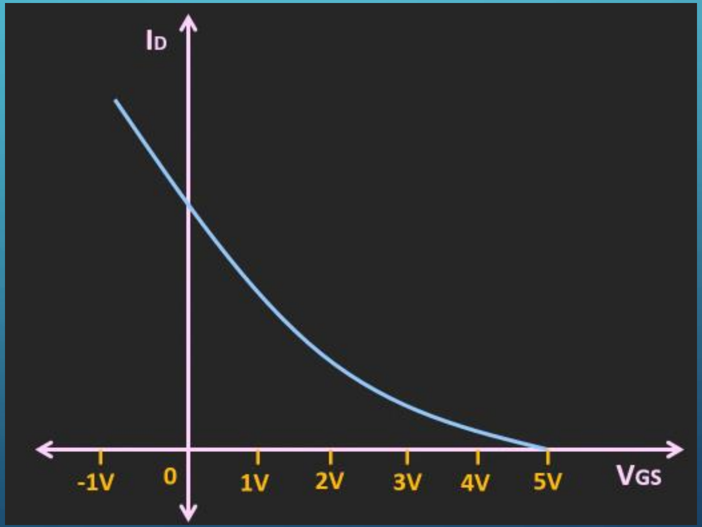
- Whenever Vgs is positive the number of free electrons on the n-channel will increase. Due to that when Vgs is positive is known as enhancement region.
- When ever Vgs becomes more negative the number of free electrons in the n-channel will decrease. Due to this when Vgs is negative is known as depletion region

P-CHANNEL DEPLETION MOSFET



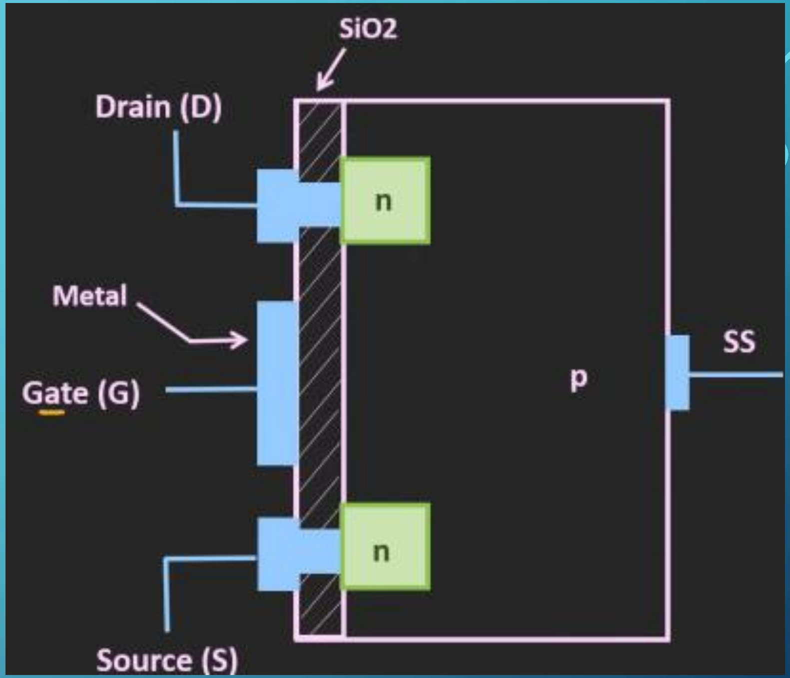






N-CHANNEL ENHANCEMENT TYPE MOSFET

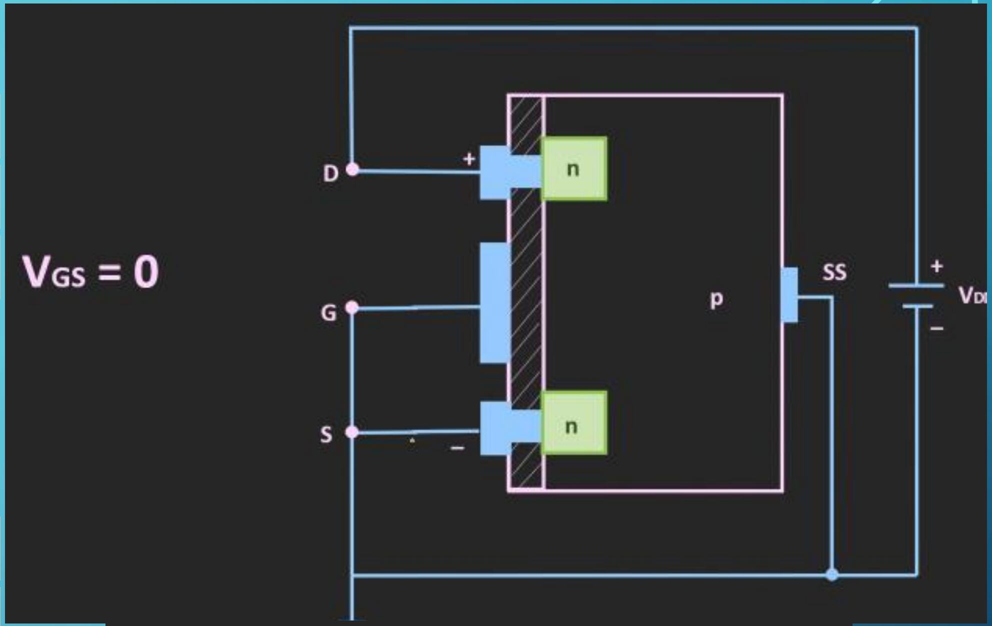
- Here unlike the depletion type MOSFET there is no channel between the drain and source terminal
- So, whenever we apply the control voltage between gate and source terminal a channel gets created between drain and source terminal.
- In this type of MOSFET the application of control voltage enhances the number of charge carriers in this region for which channel gets created and it is called enhancement type MOSFET.

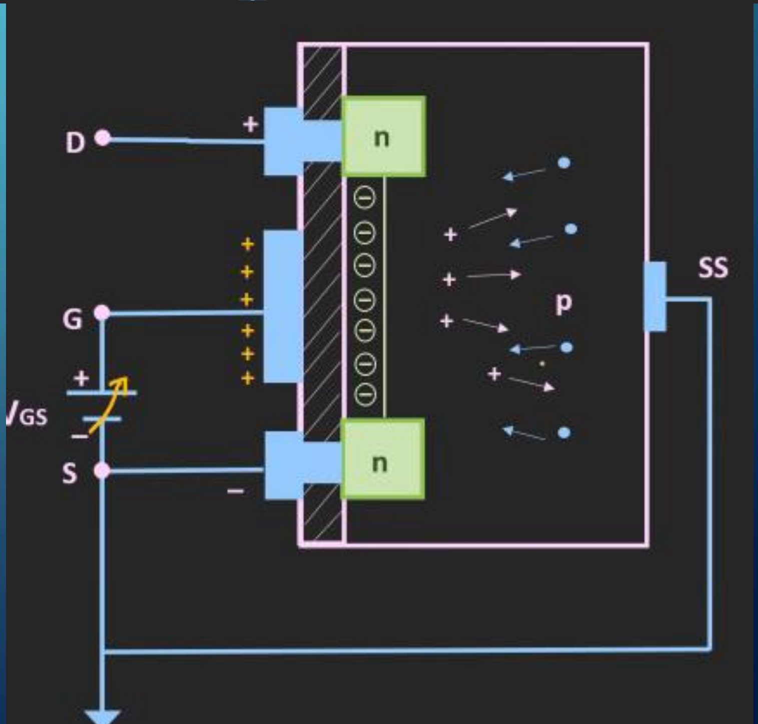


N-CHANNEL MOSFET OPERATION

- Initially lets assume Vgs=0 and a positive voltage is applied between drain and source terminal, then due to the absence of channel no current will flow through the drain to source terminal
- At this Vgs=0V, the MOSFET is on "OFF" condition.

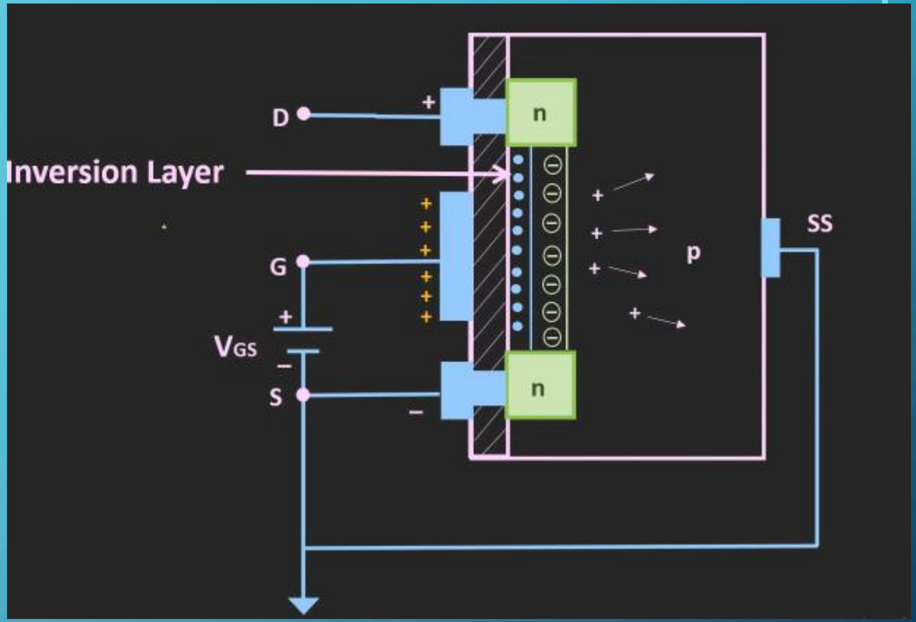
- Here, the substrate and source terminals are connected together to the ground and a positive voltage is applied between the gate and source terminal.
- For a moment lets consider Vds=0V, Now holes are the majority carriers in the p-type substrate. And when positive voltage is applied to the gate terminal, holes in the SS near the oxide terminal get pushed from the gate terminal.
- At the same time the minority electrons in the SS will get attracted towards the gate terminal





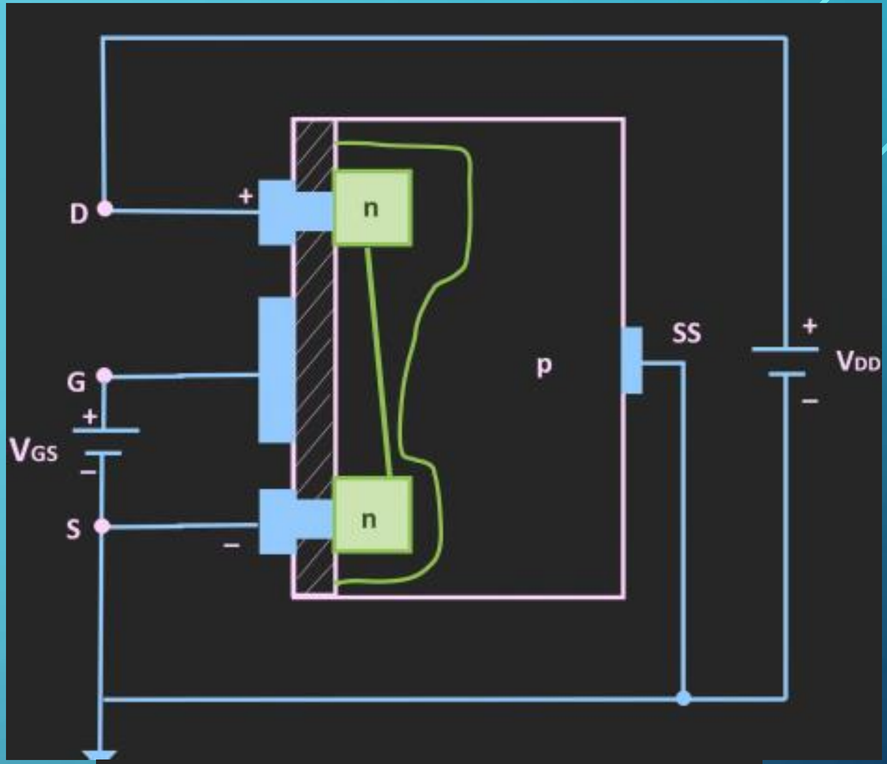
N-CHANNEL MOSFET OPERATION

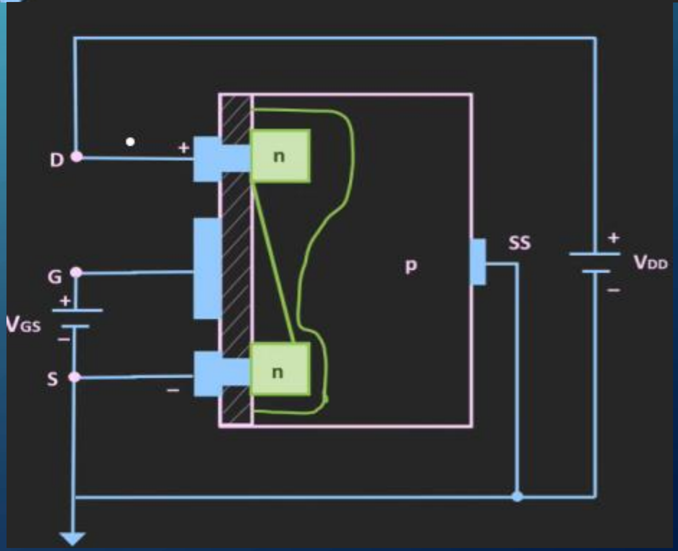
- But at the lower voltage of Vgs, the electrons will get recombined with the holes.
- As we keep increasing the Vgs, holes will be pushed deeper into the SS and the electrons will be able to overcome the recombination of these holes and they will rush towards the gate terminal
- But they will not be able to cross the oxide layer and they start accumulation near the oxide layer.
- So, eventually the inversion layer/ channel of free electrons will get created near the oxide layer
- Now, if Vds is applied then current starts flowing
- The voltage, Vgs at which channel gets created is called threshold voltage, Vt
- If Vgs<Vt, MOSFET will be off
- If Vgs> Vt, the channel width will increase



N-CHANNEL MOSFET OPERATION

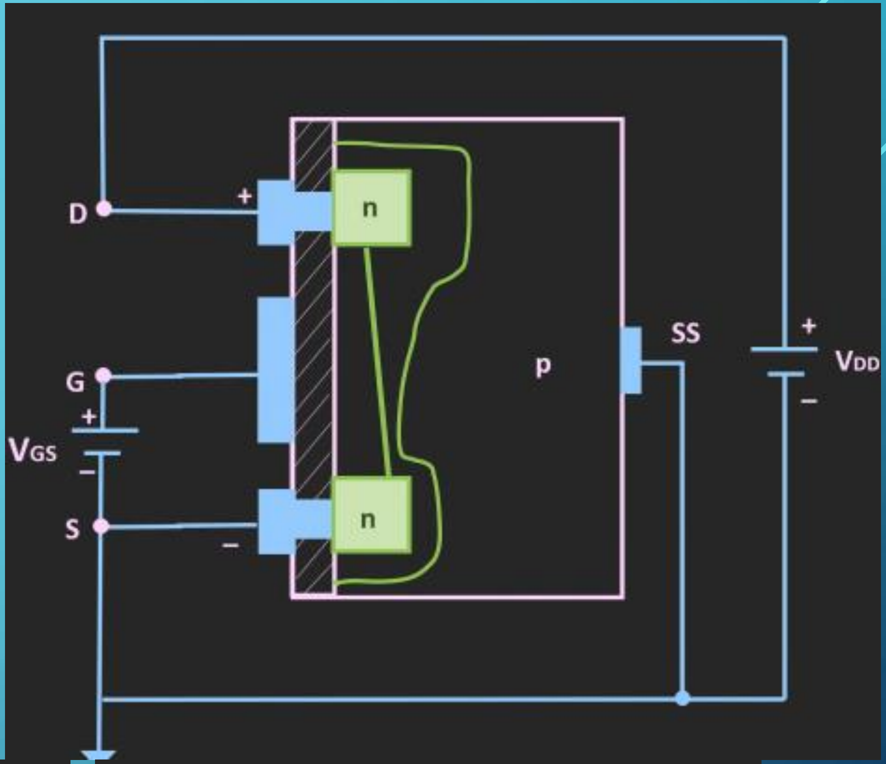
- Along with this channel there will also be a depletion layer around this channel. As if you observe there are two PN junctions which are reverse biased.
- First PN junction is between drain and SS, the other is between SS and Source.
- Now we consider Vgs>Vt, when Vds is applied the electrons get attracted towards the positive terminal and this way Id will establish in the circuit.
- But the width of the channel has been reduced towards the drain terminal. Because now the positive voltage at the drain terminal, the upper PN junction will get more reverse biased. Due to that depletion region width will increase. For that the effective channel width towards the drain terminal will reduce.
- If we keep on increasing the voltage Vds, at one particular voltage pinch off condition will occur.

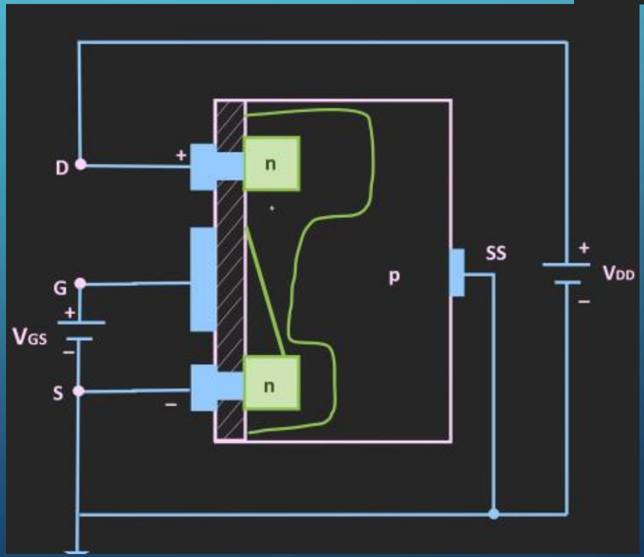


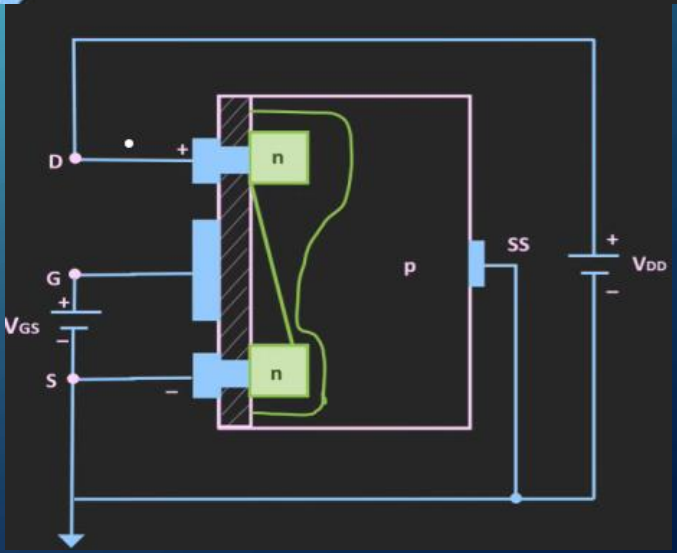


N-CHANNEL MOSFET OPERATION

- At that particular voltage, the drain current will get saturated.
- The voltage at which pinch off condition occurs is called saturation voltage (Vds(sat)).
- The saturation voltage can be expressed as Vds(sat)=Vgs-Vt
- So, for fixed value of Vgs, if we increase Vds then the difference between drain and gate terminal will be lesser than the threshold voltage. Due to which channel will not be formed to wards the drain terminal

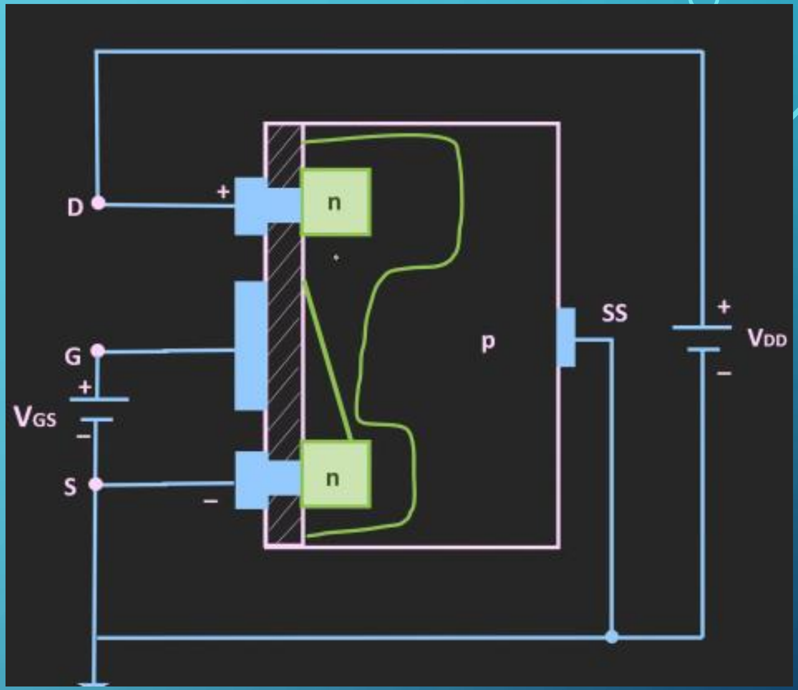


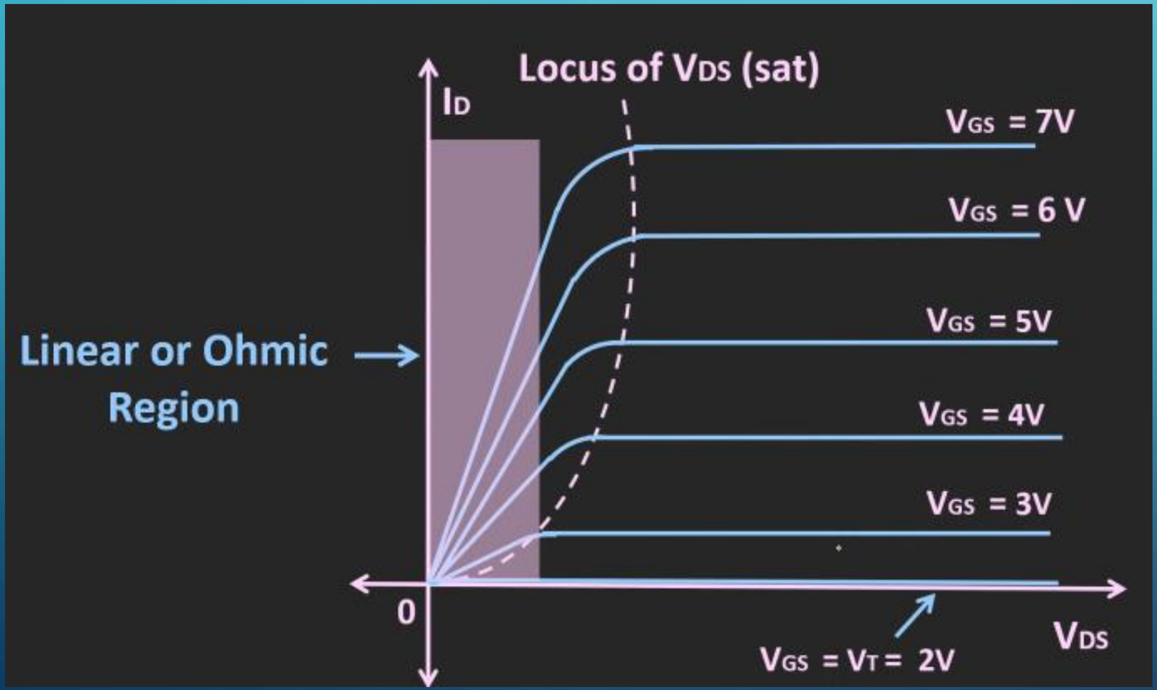




N-CHANNEL MOSFET OPERATION

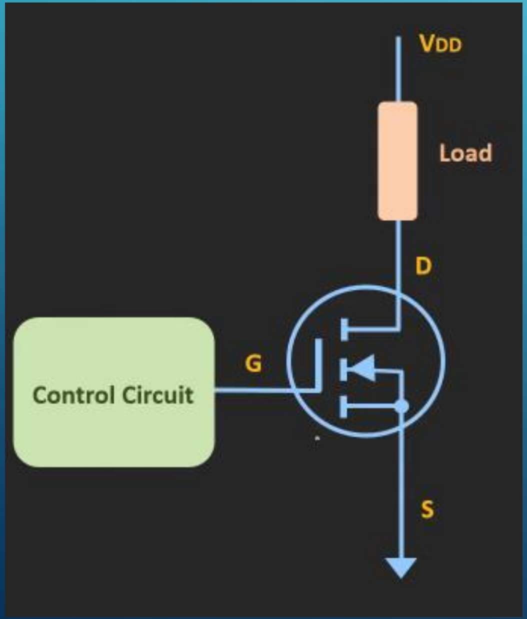
- So, it appears that Id current will be 0
- But still current will flow through the channel and this current Id will get saturated. Because the electrons passing through the channel can still be able to cross the depletion layer due to the electric force.
- So once pinch off condition occurs Id gets saturated.

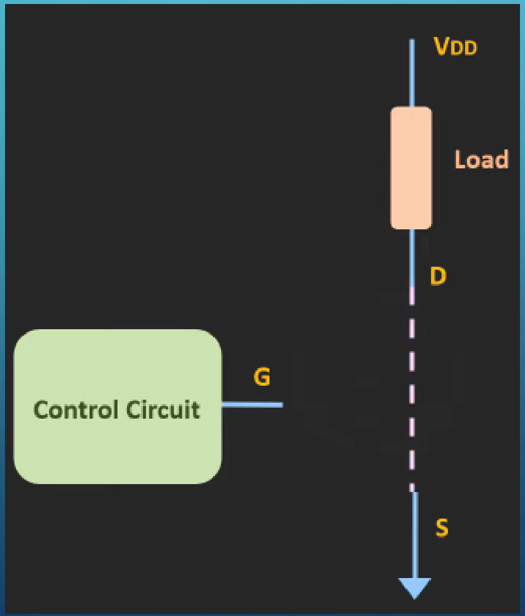


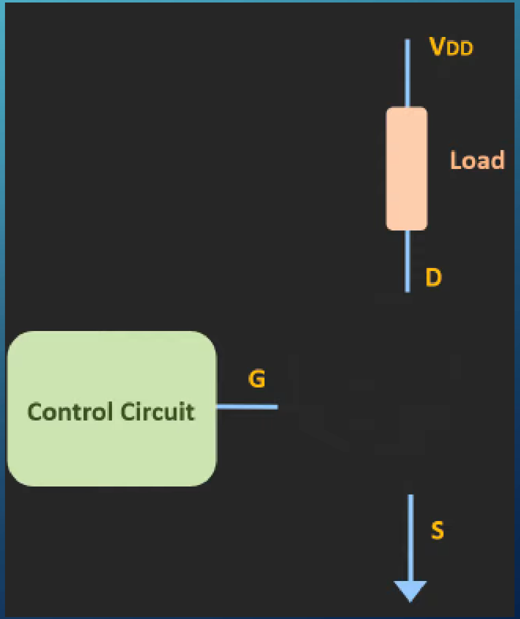


MOSFET AS A SWITCH

1. **Turning ON**: To turn the MOSFET on as a switch, you typically apply a voltage (Vgs) greater than the threshold voltage (Vth) between the gate and the source. This creates an electric field in the channel region under the gate, attracting charge carriers (electrons for NMOS) and forming a conducting channel between the source and drain. As a result, current can flow from the source to the drain.
2. **Turning OFF**: To turn the MOSFET off, you reduce the gate-source voltage (Vgs) below the threshold voltage (Vth). This depletes the charge carriers in the channel region, effectively pinching off the channel and preventing current flow between the source and drain. The MOSFET is now in its off state, acting as an open circuit between the source and drain.







DEPLETION-TYPE MOSFETS ARE NOT COMMONLY USED AS SWITCHES FOR SEVERAL REASONS:

1. **Natural Conductivity**: Depletion-type MOSFETs inherently have a conducting channel even with zero gate-source voltage. This is due to the presence of dopants in the channel region, which results in the channel being formed by default. As a result, even when the gate voltage is zero, there is a path for current to flow between the source and drain terminals.
2. **Limited Switching Range**: Since depletion-type MOSFETs have a conducting channel without any gate voltage, their ability to effectively switch between on and off states is limited. Even when you apply a negative gate voltage to try to turn off the device, the conducting channel still exists, although its conductivity may decrease.
3. **Higher Power Consumption**: Because depletion-type MOSFETs have a conducting channel even when no gate voltage is applied, they can consume more power compared to enhancement-type MOSFETs when used as switches. This is because there may still be some current flowing through the device even in its off state, leading to higher power dissipation.
4. **Limited Control**: The control over the depletion-type MOSFET as a switch is not as precise as with enhancement-type MOSFETs. Enhancement-type MOSFETs have a wider range of gate voltage control over the conductivity of the channel, allowing for more precise switching between on and off states.

Thank You!