ELECTRONIC DEVICES & CIRCUITS
Module 2

MOSFETs

S3 CSE KTU

prepared by

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MOSFETs

JFET

Unbiased condition- Both the channel and depletion regions are present in the device.
We can only decrease the width of the channel from its zero-bias size by reverse biasing the Gate (negative gate operation for n-channel and positive gate operation for p-channel)

Depletion-mode operation

The device is normally ON at zero gate–source voltage - free electrons flow from source to drain through the already existing channel when a Vds is applied. The drain current can be controlled by varying depletion of charge carriers in the channel.
This type of operation is known as depletion-mode operation.
Therefore a JFET by default is a depletion mode device.

There is a type of FET that can be used in both depletion and enhancement modes - MOSFET

The metal–oxide–semiconductor field-effect transistor (MOSFET, MOS-FET, or MOS FET) is a type of transistor used for amplifying or switching electronic signals.

Although the MOSFET is a four-terminal device with source (S), gate (G), drain (D), and body (B) terminals, the body (or substrate) of the MOSFET is often connected to the source terminal, making it a threeterminal device like other field-effect transistors.

There are two types of D-MOSFETs :

1. n-channel D-MOSFET
2. p-channel D-MOSFET

The source terminal is normally connected to ground.

Capacitive effect

A thin layer of oxide, usually silicon dioxide (SiO2) is deposited over a small portion of the channel. This acts as an insulator.

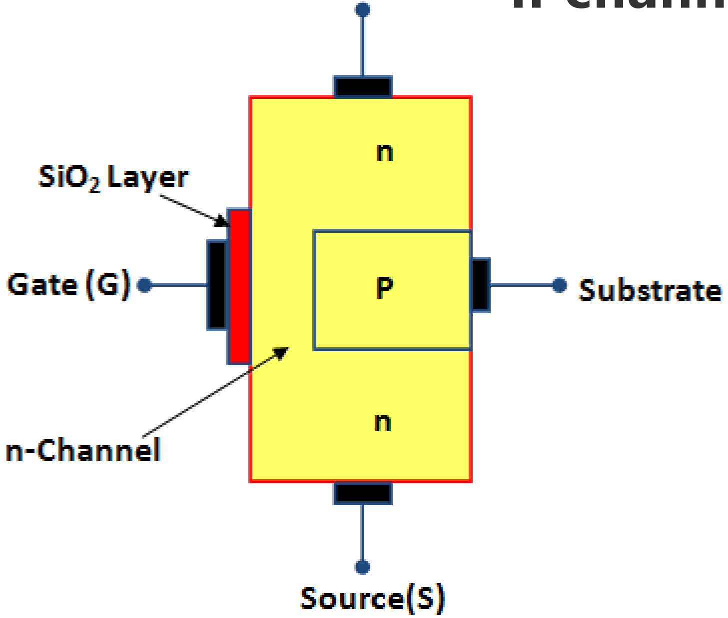
MOS transistor has either a **metal gate (an older technology**), or more usually a **polysilicon-gate (a newer technology**), built on top of the insulating gate oxide..

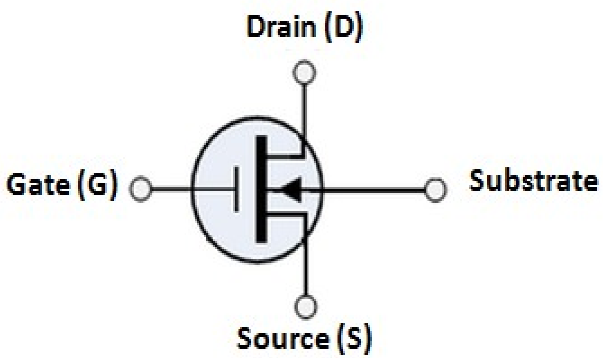
Gate and channel acts as capacitor plates and the oxide layer as dielectric.

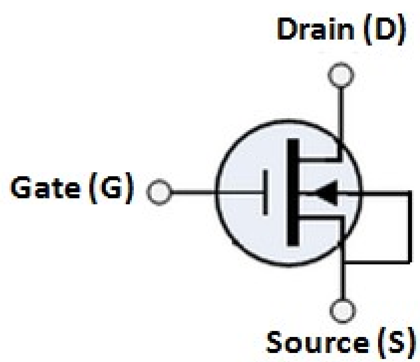
The capacitor plays an essential role for operating a MOSFET.

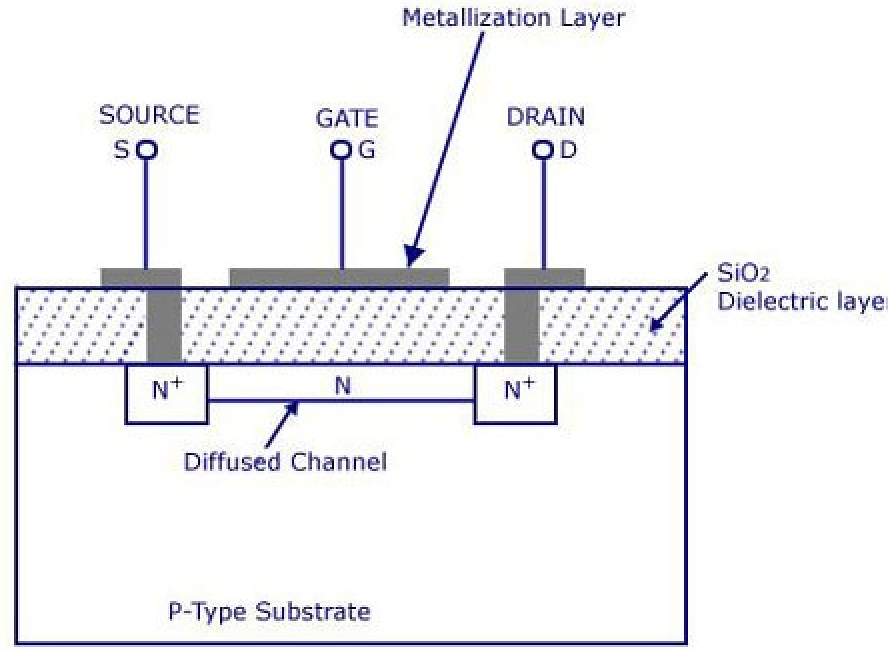
We also call the device as Insulated Gate Field Effect Transistor (IGFET) or Metal Insulator Field Effect Transistor (MIFET)

n-channel D-MOSFET









N-Channel DE-MOSFET Structure

In n-channel MOSFET, conduction occurs through electrons, which are the majority carriers for that device. They emerge from the source terminal and are attracted to drain which is positive; hence, the arrow indicates movement from source to drain.

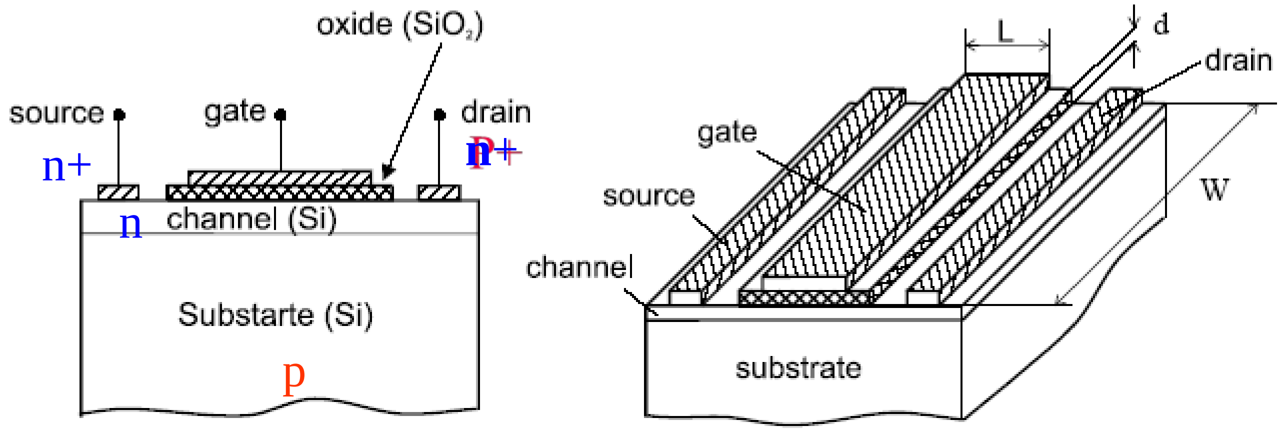
The gate appears like a capacitor plate.

The thick vertical line represents the channel.

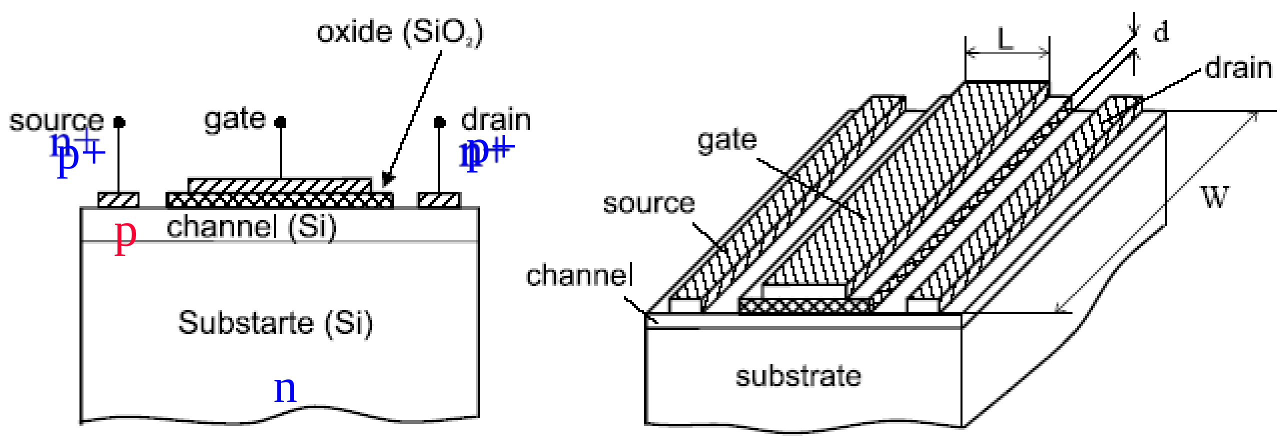
The substrate is connected to the source

This gives rise to a three terminal device.

n-channel depletion
Metal-Oxide-Semiconductor FET (MOSFET)



p-channel depletion
Metal-Oxide-Semiconductor FET (MOSFET)



STRUCTURE OF n-channel D-MOSFET

The n-channel D-MOSFET is a piece of **heavily doped n-type source and drain regions** with a p-type region called substrate on the right and an insulated gate on the left

The space between source and drain regions is diffused by normally doped n-type impurities.

The channel lies between the gate and the p-type region (i.e. substrate)

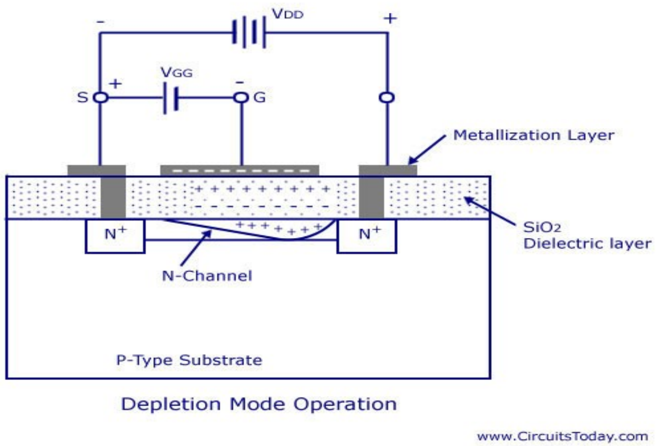
A thin layer of oxide, usually silicon dioxide (SiO_2) is deposited over a small portion of the channel. This acts as an insulator.

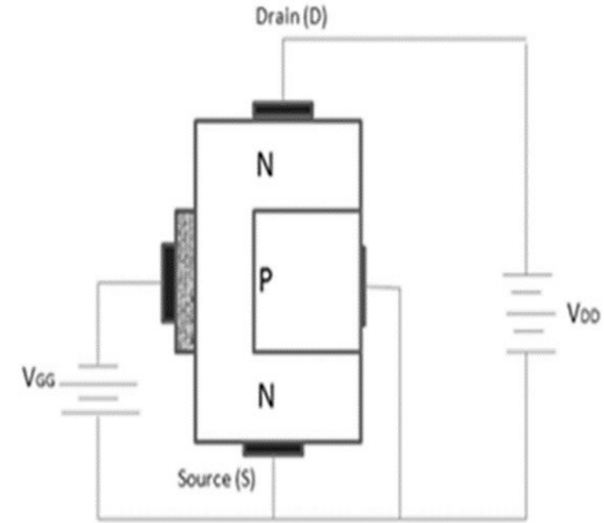
MOS transistor has either a **metal gate (an older technology**), or more usually a **polysilicon-gate (a newer technology**), built on top of the insulating gate oxide.
Gate and channel acts as capacitor plates and the oxide layer as dielectric.

As SiO_2 is an insulator, gate is insulated from the channel. Due to this i/p resistance is very high compared to JFET

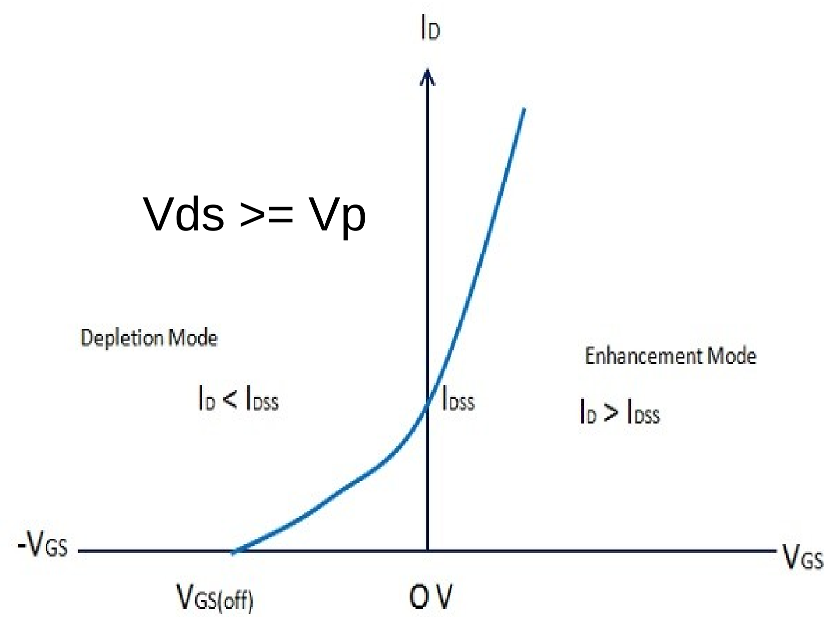
The substrate(B) is connected to the source internally so that a MOSFET has three terminals such as Source (S), Gate (G) and Drain(D).

n-channel D-MOSFET Depletion Mode Operation



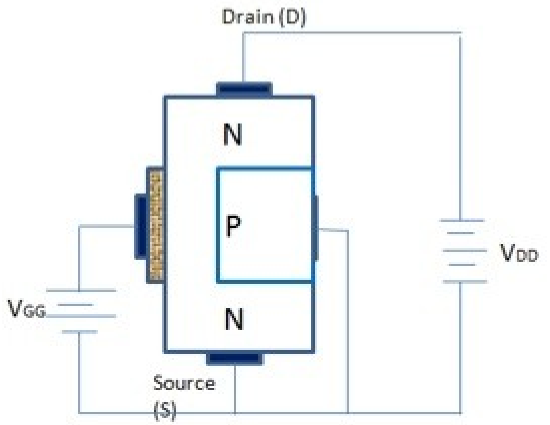


The device is normally ON at zero gate–source voltage
Free electrons flow from source to drain through the already existing channel when a Vds is applied.
The drain current can be controlled by varying depletion of charge carriers in the channel.
The depletion-mode operates by applying a more negative gate voltage than the threshold voltage $-V_{TH}$ or $-V_{GS}$ (off).
Due to the capacitive effect, the free electrons under the oxide layer get repelled and shifted downward to the n region which has the effect of “depleting” or shutting off the majority current carriers in the pre-formed channel beneath the gate.
Therefore we call it as depletion MOSFET.
For a depletion-mode MOSFET the channel is fully conductive and current flows strongly between the drain and source when the gate terminal is at zero volts ($V_{GS} = 0V$).
An increasingly negative bias at the gate of an N-channel device will reduce conduction in the channel, until finally $-V_{GS}$ (off) - the device’s threshold voltage V_{TH} is reached, and conduction ceases.
Thickness and position of the channel is controlled by a combination of the gate-to-source voltage (V_{GS}), and the drain-to-source voltage (V_{DS}). These effectively change the resistance in the channel, allowing full, partial, or no conduction.



n-channel D-MOSFET

Enhancement Mode of operation



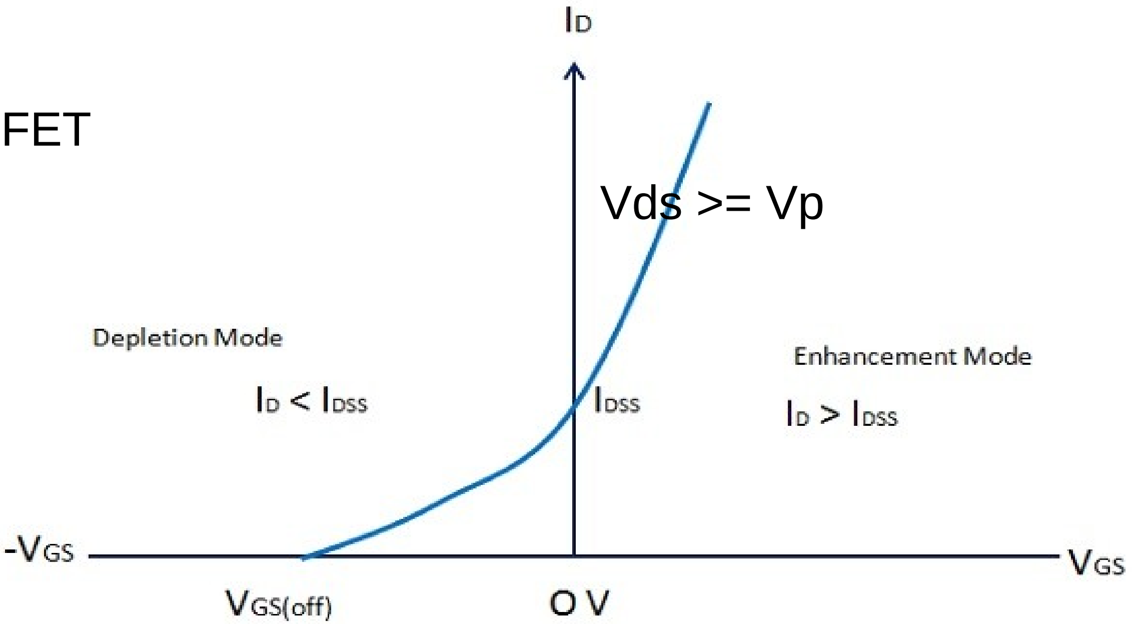
The figure shows n channel D MOSFET under enhancement mode of operation.
Here, the gate acts as a capacitor.
However, in this case the gate is positive.
It provokes the electrons in the n channel and the number of electrons increases in the n channel.

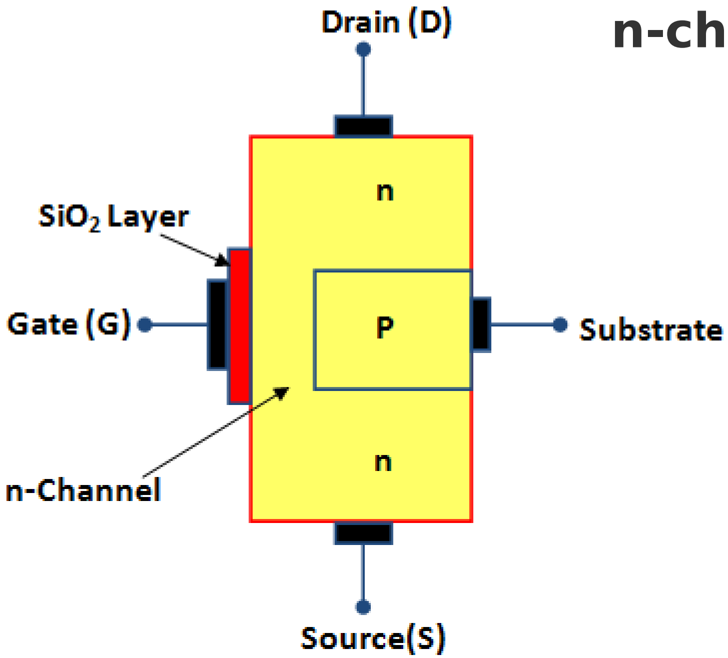
A positive gate voltage enhances or increases conductivity of the channel. The larger the positive voltage on the gate, greater the conduction from the source to the drain.

Thus, we can change the resistance of the n channel and the current from the source to the drain by varying the positive voltage on the gate.

Transfer Characteristics of D- MOSFET

$$I_D=Idss(1-V_{GS}/Vp)^2$$





n-channel D-MOSFET

Importance of the gate capacitance

The gate forms a small capacitor. One plate of this capacitor is the gate and the other plate is the channel with metal oxide layer as the dielectric.

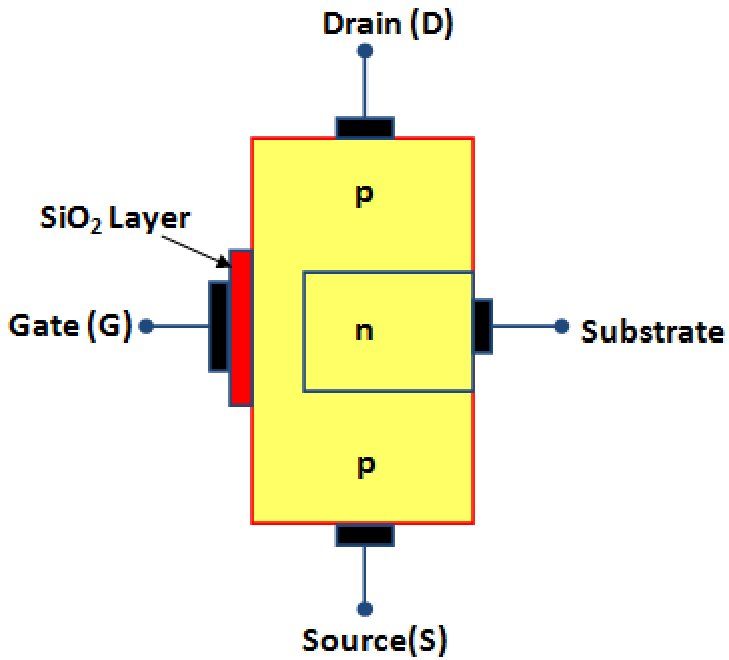
When gate voltage is changed, the electric field of the capacitor changes which in turn changes the resistance of the n-channel.

The source to drain current is controlled by the electric field of capacitor formed at the gate

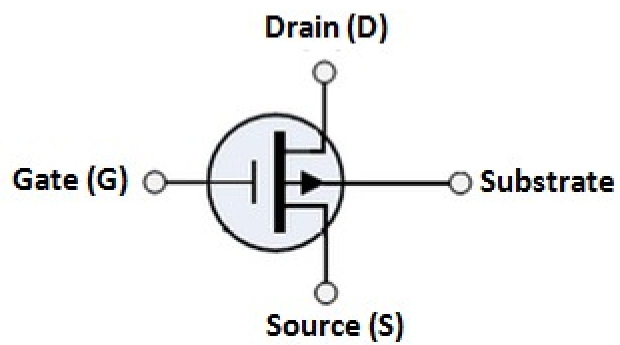
1. As the gate of D-MOSFET forms a capacitor, negligible gate current flows whether positive or negative voltage is applied to the gate. For this reason, the input impedance of D-MOSFET is very high ranging from 10,000 MΩ to 10,000,00 MΩ.

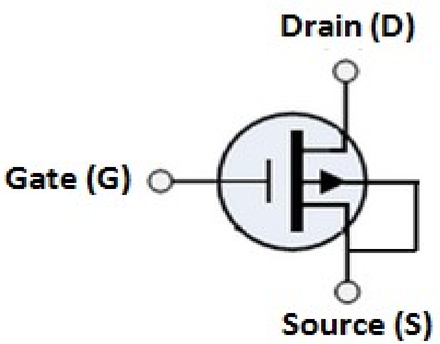
1. The extremely small dimensions of oxide layer under the gate terminal results in a very low capacitance and the D-MOSFET has, therefore, a very low input capacitance. This characteristics makes the D-MOSFET useful in high frequency applications.

p-channel D-MOSFET



A heavily doped p-type material serves as the channel and the substrate is of n-type.
The conduction takes place by the flow of holes from source to drain through this narrow channel.



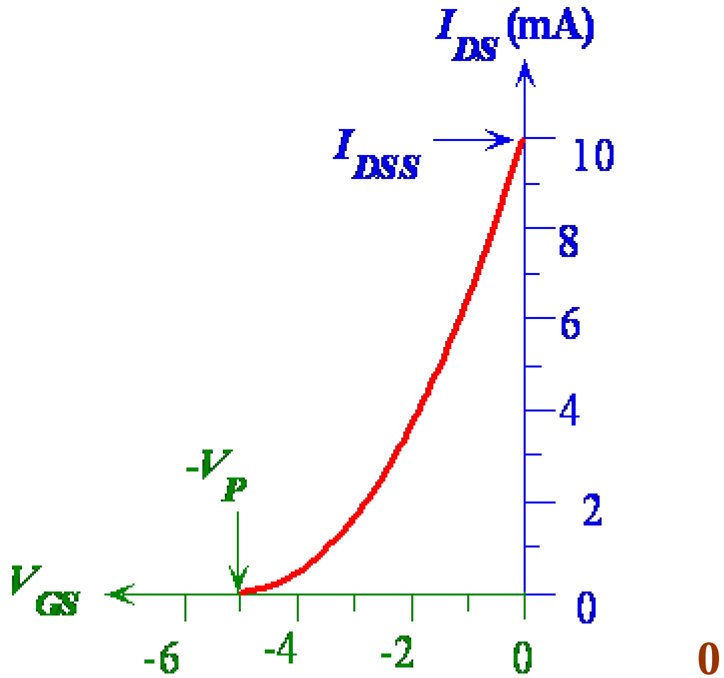


In p-channel MOSFET, conduction occurs through holes, which are the majority carriers for that device. Holes are positive and they attract to the negative side, hence the arrow indicates movement from drain to source.

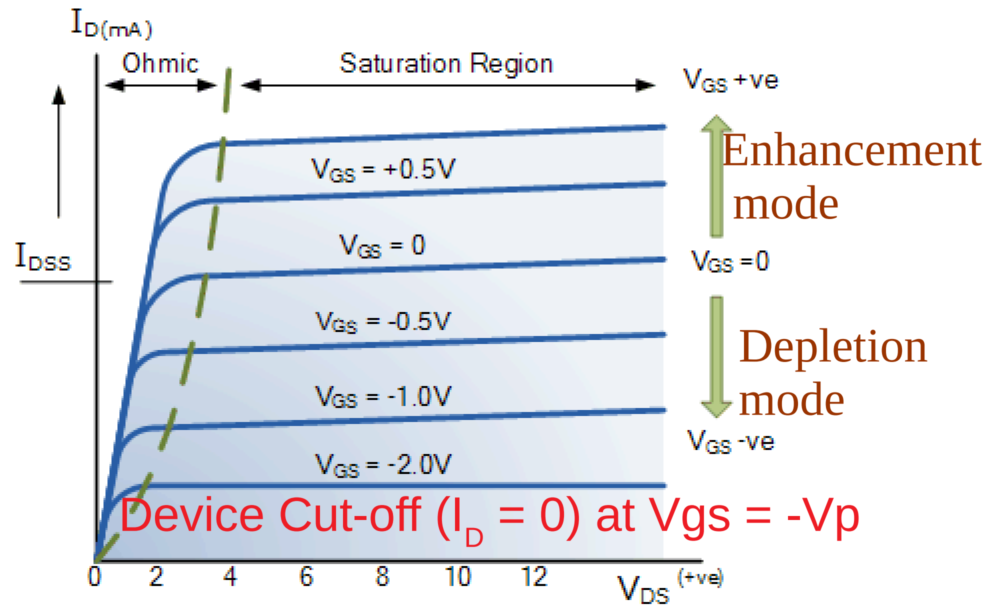
D-MOSFET can work in two modes –Depletion and Enhancement modes

we can apply either negative or positive voltage to the gate.
The negative gate operation is called *depletion mode* and positive gate operation is called *enhancement mode*.
When negative gate voltage is applied the channel gets further depleted of free majority carriers (electrons for n-channel).
When positive gate voltage is applied the channel gets further enhanced of free majority carriers (electrons for n-channel).

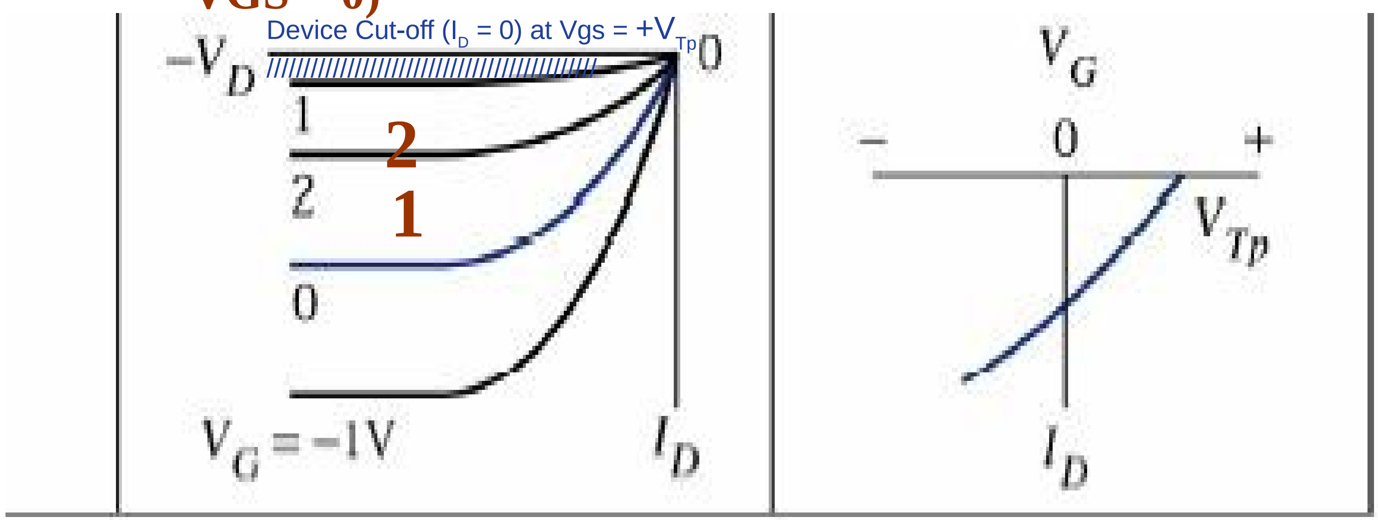
Transfer Characteristics of n-channel D- MOSFET in depletion mode



Drain Characteristics(O/P Chara) of n-channel D- MOSFET in depletion & enhancement modes

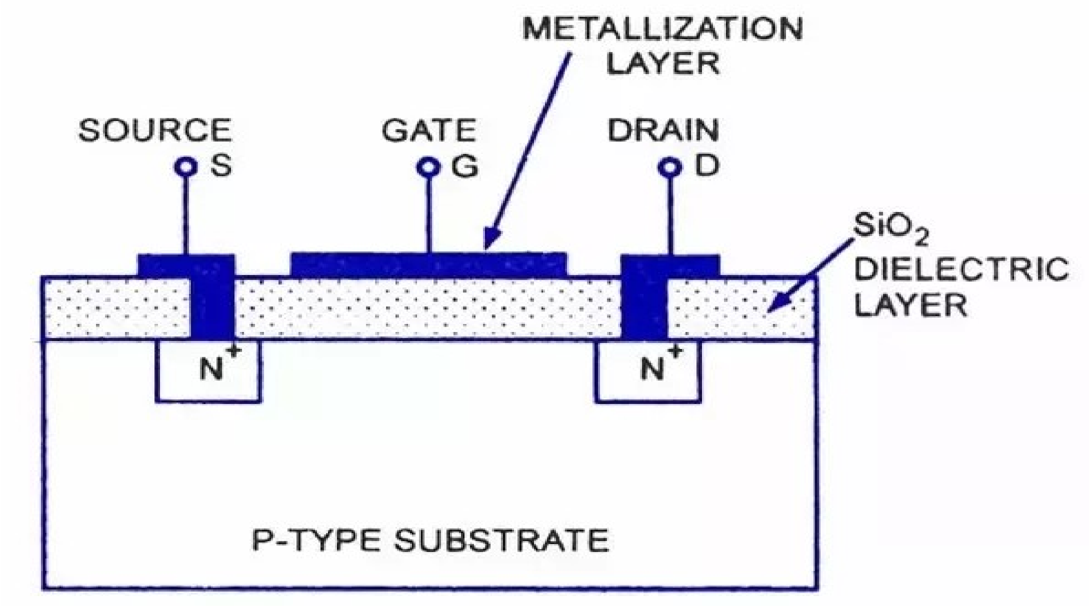


p-channel depletion MOSFET (Normally ON at VGS = 0)



P-channel D-MOSFET $+V_{tp}$ is the voltage to be applied across GS for the device to be completely cut -off. Equal to pinch -off voltage applied across DS (-Vds) for saturation

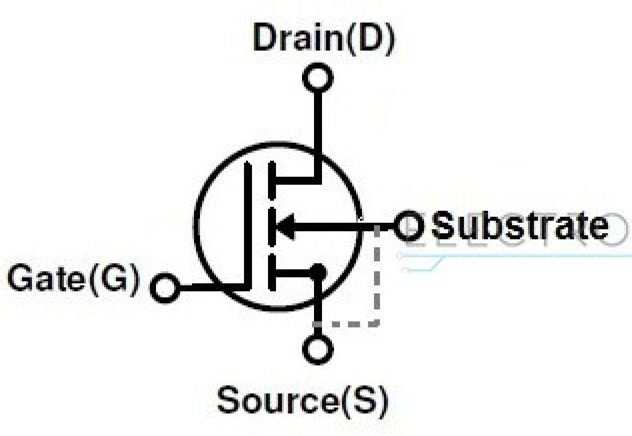
Enhancement-type MOSFET/ E- MOSFET- structure



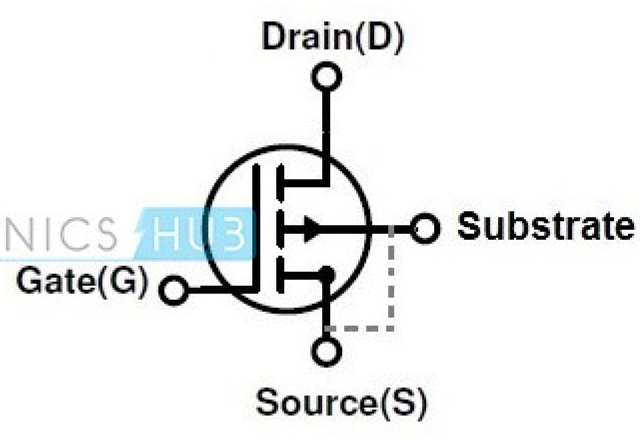
N-Channel E-MOSFET Structure

In N Channel Enhancement MOSFET a lightly doped p-type substrate forms the body of the device

Source and Drain regions are heavily doped with n-type impurities. E-MOSFET substrate extends all the way to the silicon dioxide (SiO2) and no channels are doped between the source and the drain. ***Channels are electrically induced in these MOSFETs, when a positive gate-source voltage V_{GS} is applied to it.***

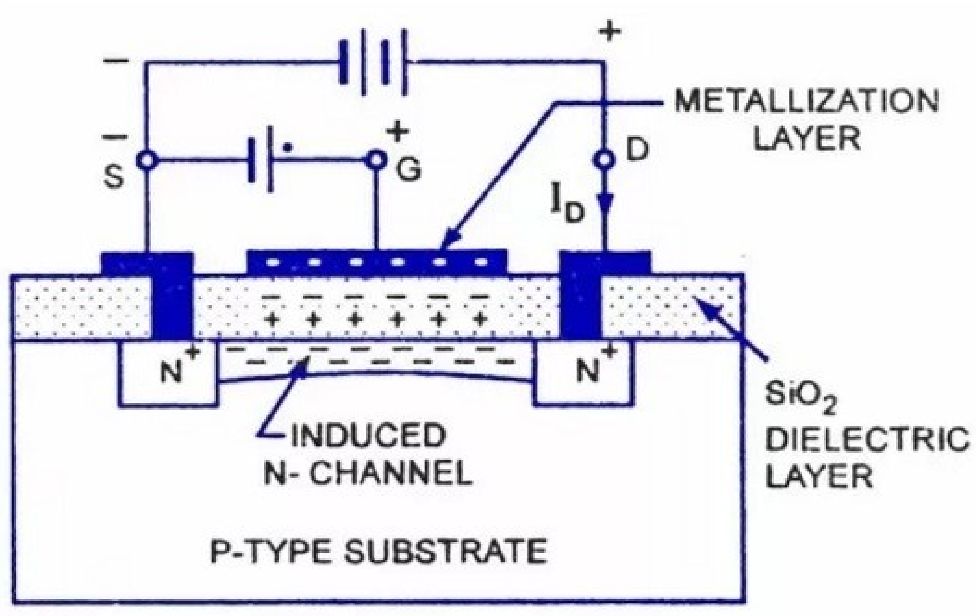


n-channel E-MOSFET



p-channel E-MOSFET

Working of N - Channel Enhancement MOSFET



Operation of N-Channel E-MOSFET

The body and source are commonly connected to the ground potential.

Formation of inversion layer

When the gate is made positive with respect to the source and the substrate, negative (i.e. minority) charge carriers within the substrate are attracted to the positive gate and accumulate close to the surface of the substrate.

As the gate voltage is increased, more and more electrons accumulate under the gate. Since these electrons can not flow across the insulated layer of silicon dioxide to the gate, they accumulate at the surface of the substrate just below the gate.

These accumulated minority charge carriers form an ***N -type channel stretching from drain to source***. This is termed as ***inversion layer (N-type)***. The free electrons also come from the heavily doped source and drain n-type region.

Working of N - Channel Enhancement MOSFET contd...

Only one mode - Enhancement mode of operation

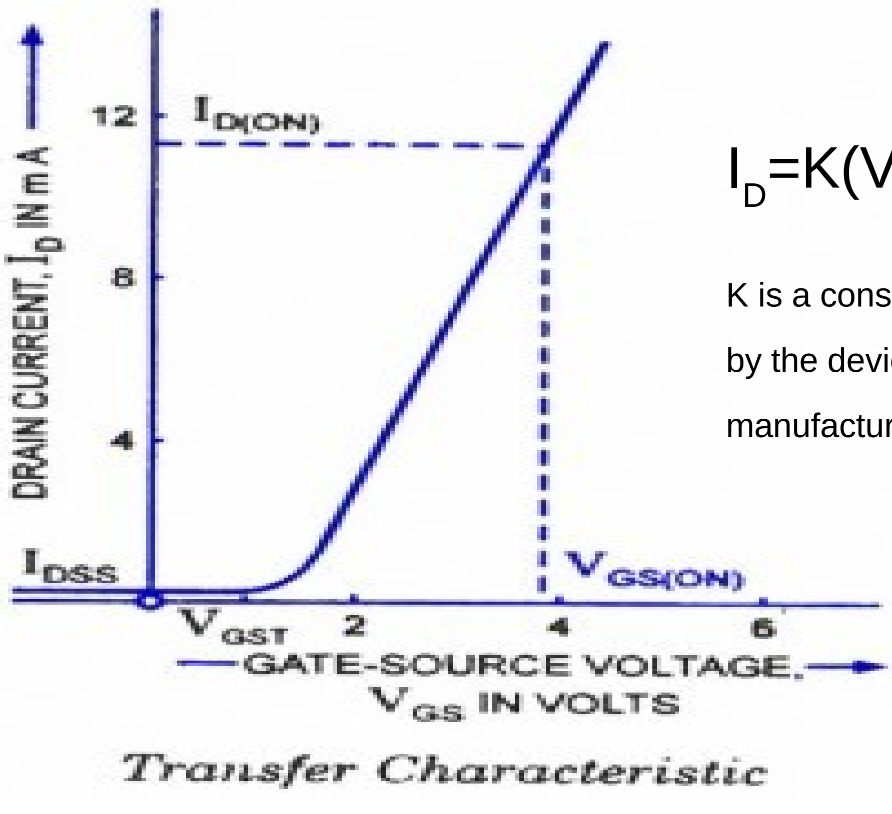
When a positive voltage is applied at the drain, current start flowing through the channel. As the concentration of free electrons forms the channel and the current through the channel gets enhanced due to increase in gate voltage, we name the MOSFET as N - Channel Enhancement MOSFET.
As its name indicates, this MOSFET operates only in the enhancement mode and has no depletion mode. It operates with large positive gate voltage only.The strength of the drain current depends upon the channel resistance which, in turn, depends upon the number of charge carriers attracted to the positive gate. Thus drain current is controlled by the gate potential.

E-MOSFET is a Normally Off device

It does not conduct when the gate-source voltage VGS = 0. This is the reason that it is called normally-off MOSFET. In these MOSFET's drain current I_D flows only when V_{GS} exceeds V_{GST} [gate-to-source threshold voltage] or V_T

Enhancement-type MOSFET/ E- MOSFET

In case of an enhancement-type MOSFET, the gate-to-source voltage must exceed a threshold value for forming a channel so that current flow ensues on application of a positive drain-to-source voltage. The minimum value of gate-to-source voltage V_{GS} that is required to form the inversion layer (N-type) is termed the gate-to-source threshold voltage V_{GST} (V_T). For V_{GS} below V_{GST}, the drain current $I_D = 0$. But for V_{GS} exceeding V_{GST} an N-type inversion layer connects the source to drain and the drain current I_D is large. Depending upon the device being used, V_{GST} may vary from less than 1 V to more than 5 V.

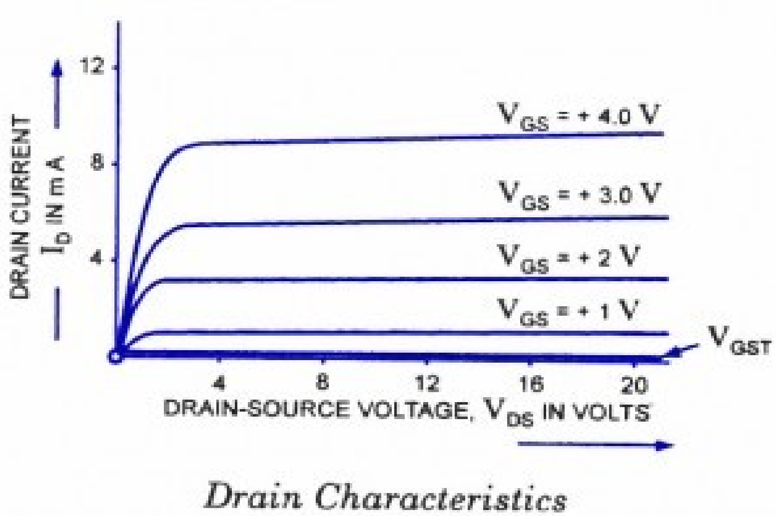


$$I_D = K(V_{GS} - V_{GST})^2$$

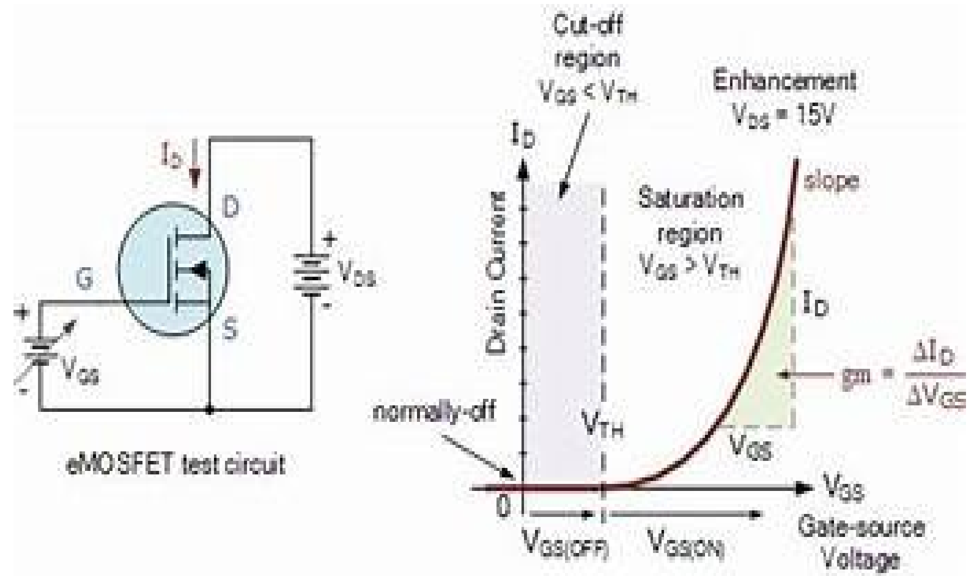
K is a constant provided by the device manufacturer

JFETs and D-MOSFETs are classified as the depletion-mode devices because their conductivity depends on the action of depletion layers.
E-MOSFET is classified as an enhancement-mode device because its conductivity depends on the action of the inversion layer.
Depletion-mode devices are normally ON when the gate-source voltage VGS = 0, whereas the enhancement-mode devices are normally OFF when VGS = 0.
The basic structure of the MOSFET is different in the two cases (distinguished by the presence of absence of the n-channel).
Interconversion between the two is not possible.
Behavior of the two is identical when the enhancement-type MOSFET is operated above threshold and the depletion-type MOSFET is operated above pinch- off voltage.
Both Id-Vgs graphs represent a parabolic dependence, in the saturation condition of operation.

Drain Characteristics(O/P Chara) of n-channel E- MOSFET



Transfer Characteristics of n-channel E- MOSFET



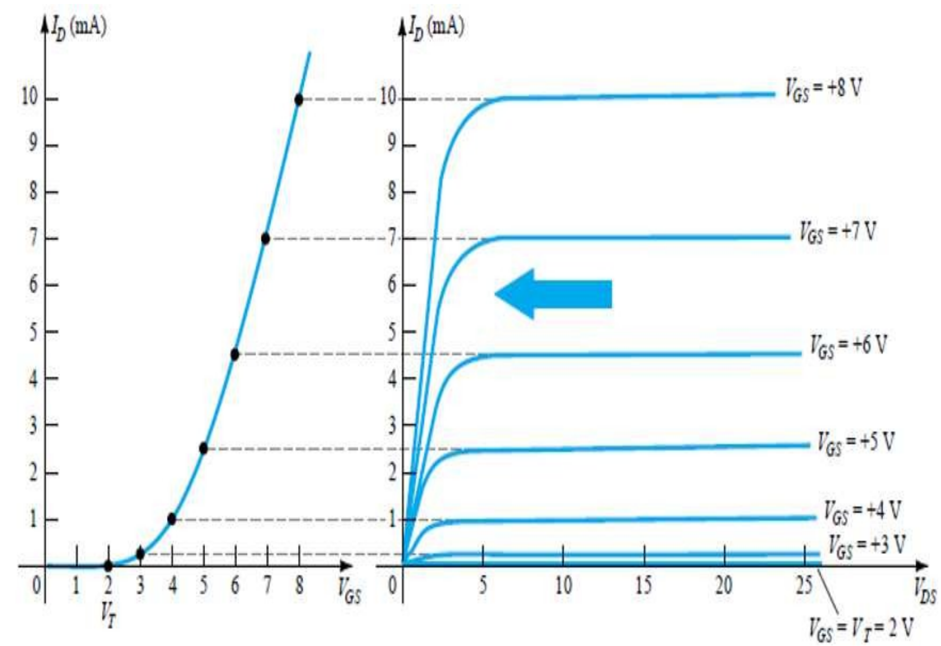
The lowest curve is the V_{GST} curve. When V_{GS} is lesser than V_{GST} approximately zero.

When V_{GS} is greater than V_{GST} , the device turns- on and the drain current I_D is controlled by the gate voltage.

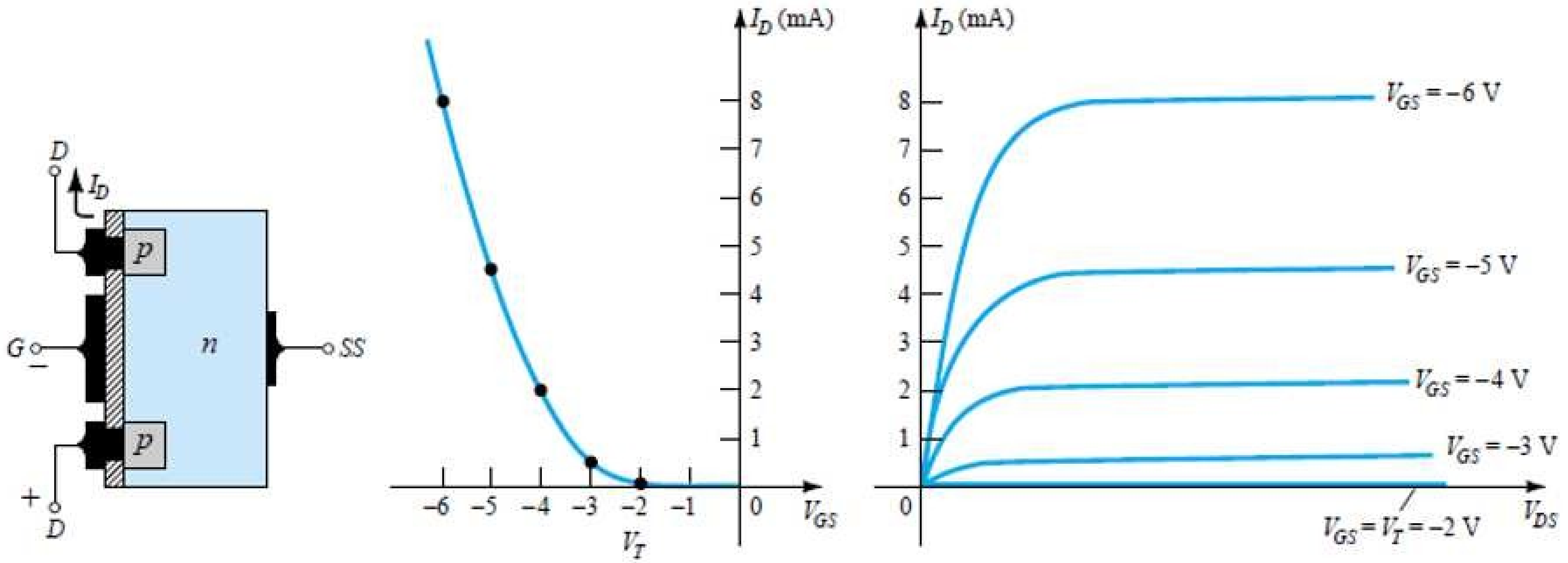
The characteristic curves have almost vertical and almost horizonta parts.

The almost vertical components of the curves correspond to the ohı region, and the horizontal components correspond to the constant current region.

Thus E-MOSFET can be operated in either of these regions i.e. it can be used as a variable-voltage resistor (WR) or as a constant current source.



p-Channel enhancement type MOSFET



Important

We can control the current from the source to drain with the help of an applied gate voltage. Hence similar to JFET, MOSFET is a voltage controlled electronic device.