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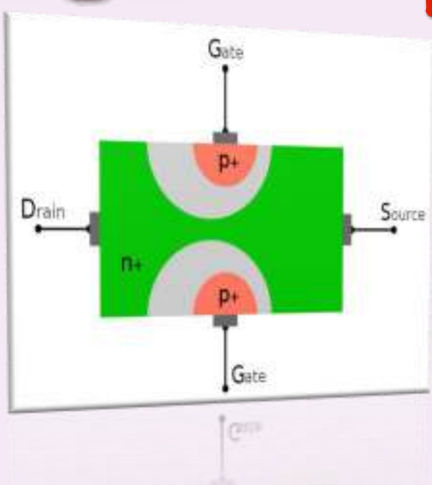

Electronic Fundamentals

Circuits, Devices, and Applications

Unit 6: Field Effect Transistor (FET)
Lecture 19: Field Effect Transistor (FET)

Dr. Hazem Falah Sakeek
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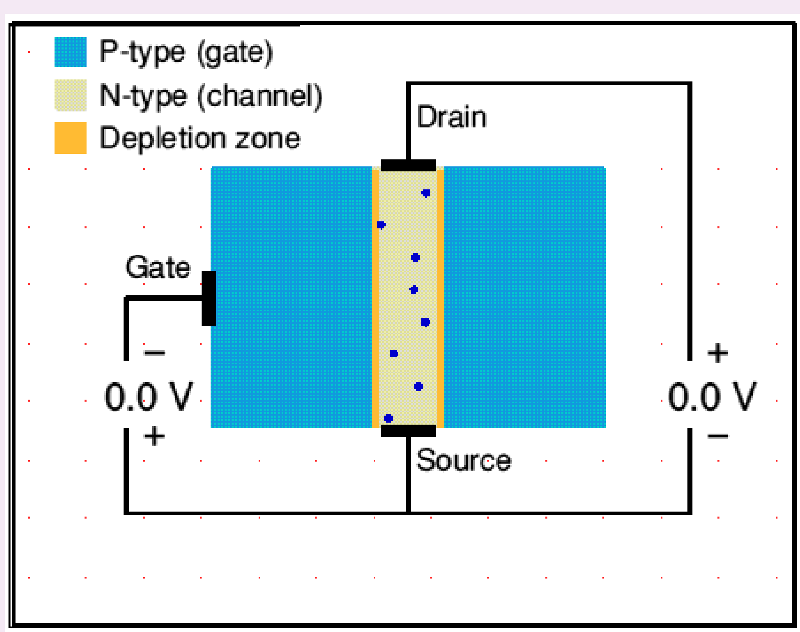

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Introduction

- In ordinary transistor, both holes and electrons play part in the conduction process. For this reason, it is called a bipolar transistor.
- The ordinary or bipolar transistor has two principal disadvantages.
  - **First,** it has a low input impedance because of forward biased emitter junction.
  - **Secondly,** it has considerable noise level, it is difficult to achieve input impedance more than a few megaohms.
- The **field effect transistor (*FET*)** has, by its construction and biasing, large input impedance which may be more than 100 megaohms.
- The *FET* is generally much less noisy than the ordinary or bipolar transistor.

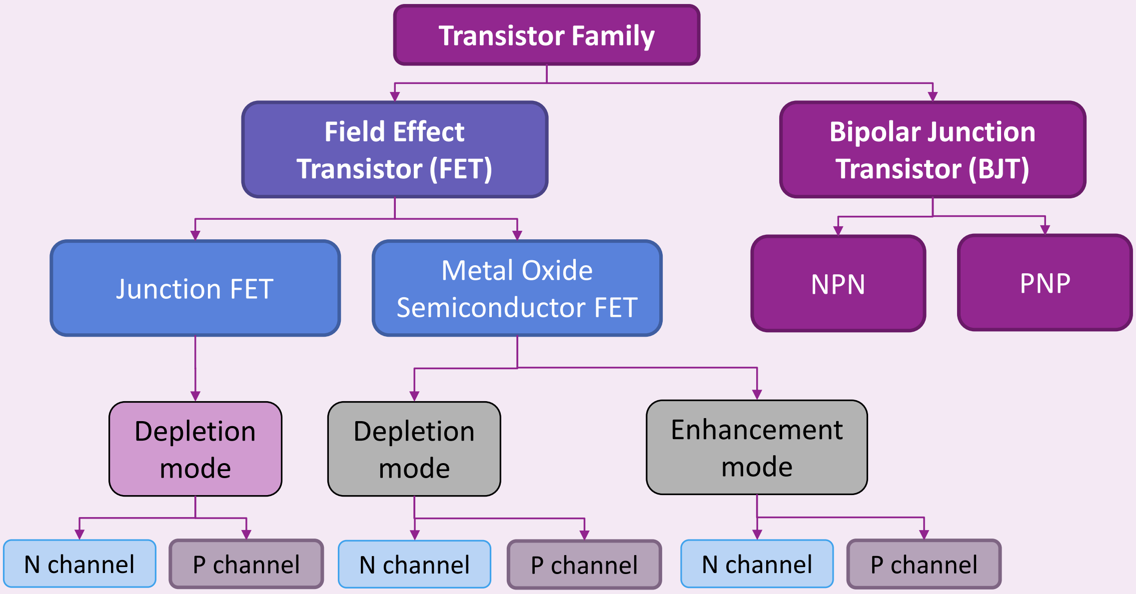
Types of Field Effect Transistors

A **bipolar junction transistor (*BJT*)** is a current controlled device *i.e.*, output characteristics of the device are controlled by base current and not by base voltage. However, in a **field effect transistor (*FET*)**, the output characteristics are controlled by input voltage (*i.e.*, electric field) and not by input current.

There are two basic types of field effect transistors:

- **(*i*) Junction field effect transistor (*JFET*)**
- **(ii) Metal oxide semiconductor field effect transistor (*MOSFET*)**

To begin with, we shall study about *JFET* and then improved form of *JFET*, namely; *MOSFET.*

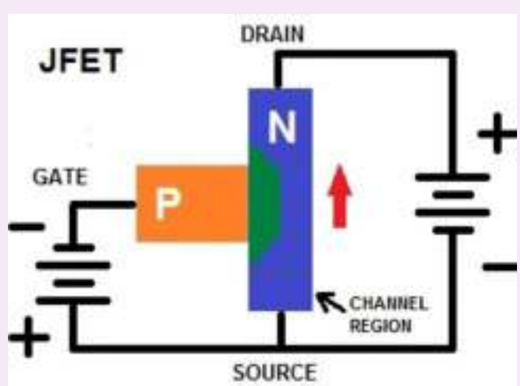


Junction Field Effect Transistor (JFET)

A **junction field effect transistor** *is a three terminal semiconductor device in which current conduction is by one type of carrier i.e., electrons or holes.*

The *JFET* was developed about the same time as the transistor but it came into general use only in the late 1960s. In a *JFET*, the current conduction is either by electrons or holes and is controlled by means of an electric field between the gate electrode and the conducting channel of the device.

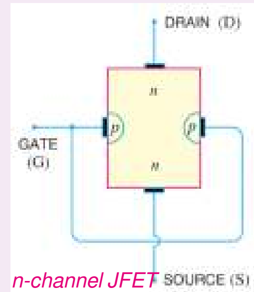
The *JFET* has high input impedance and low noise level.

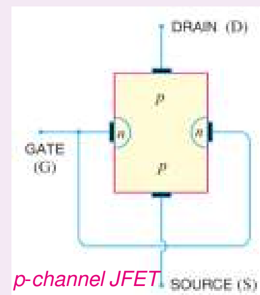


Construction of JFET

A *JFET* consists of a *p*-type or *n*-type silicon bar containing two *pn* junctions at the sides as shown. The bar forms the conducting channel for the charge carriers.

The two *pn* junctions forming diodes are connected internally and a common terminal called *gate* is taken out. Other terminals are *source* and *drain* taken out from the bar as shown. Thus a *JFET* has essentially three terminals *viz*., *gate* (*G*), *source* (*S*) and *drain* (*D*).





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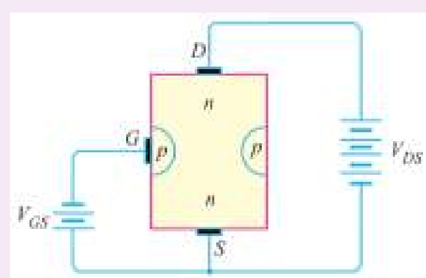
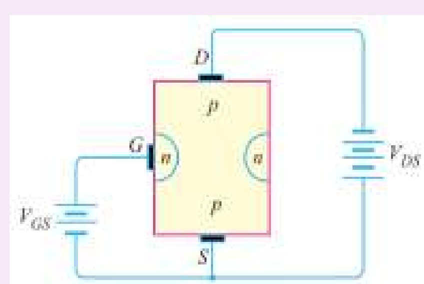
JFET polarities

The voltage between the gate and source is such that the gate is reverse biased.

The following points may be noted:

- ***(i)*** The input circuit (*i.e.* gate to source) of a *JFET* is reverse biased. This means that the device has high input impedance.
- ***(ii)*** The drain is so biased w.r.t. source that drain current I_D flows from the source to drain.
- ***(iii)*** In all *JFETs*, source current I_S is equal to the drain current *i.e.* $\mathbf{I_S = I_D}$.





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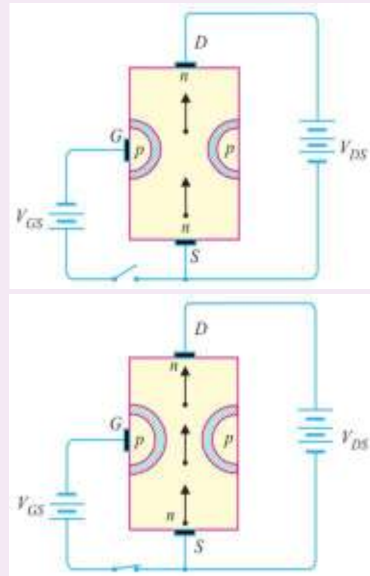
Principle and Working of JFET

The two *pn* junctions at the sides form two depletion layers. The current conduction by charge carriers (*i.e.* free electrons) is through the channel between the two depletion layers and out of the drain.

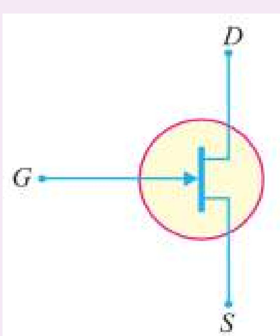
The width (resistance) of this channel can be controlled by changing the input voltage V_{GS}.

The greater the reverse voltage V_{GS}, the wider will be the depletion layers and narrower will be the conducting channel.

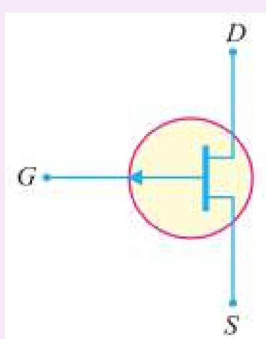
Thus JFET operates on the principle that width and hence resistance of the conducting channel can be varied by changing the reverse voltage V_{GS}. In other words, the magnitude of drain current (I_D) can be changed by altering V_{GS}.



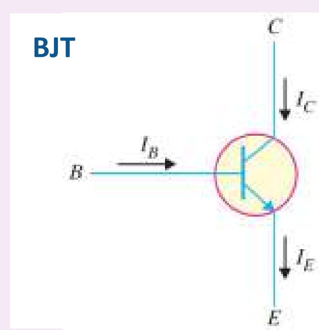
Symbol of JFET

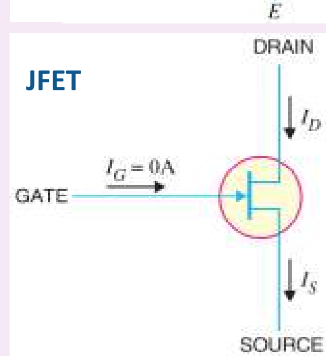


N Channel JFET



P Channel JFET





JFET as an Amplifier

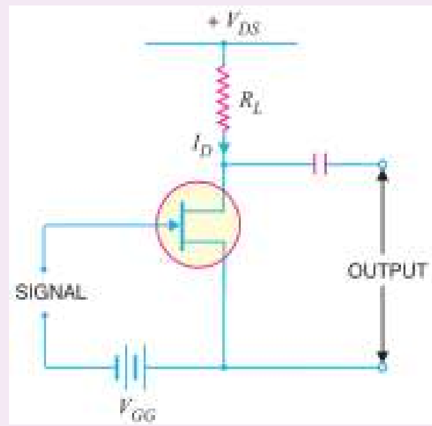
The weak signal is applied between gate and source and amplified output is obtained in the drain-source circuit. For the proper operation of *JFET*, input circuit should always be reverse biased by inserting a battery V_{GG} in the gate circuit.

A small change in the reverse bias on the gate produces a large change in drain current.

During the positive half of signal, the reverse bias on the gate decreases. This increases the channel width and hence the drain current.

During the negative half-cycle of the signal, the reverse voltage on the gate increases. Consequently, the drain current decreases.

The result is that a small change in voltage at the gate produces a large change in drain current. These large variations in drain current produce large output across the load R_L. In this way, *JFET* acts as an amplifier.



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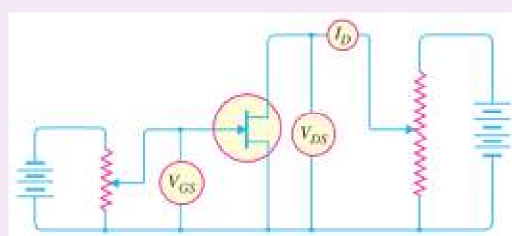
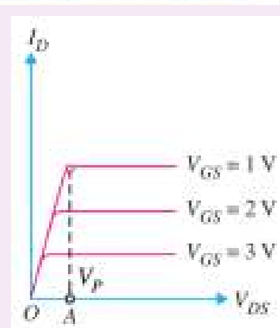
Output Characteristics of JFET

The curve between drain current (I_D) and drain-source voltage (V_{DS}) of a *JFET* at constant gate-source voltage (V_{GS}) is known as *output characteristics of JFET*.



(i) At first, the drain current I_D rises rapidly with drain-source voltage V_{DS} but then becomes constant. The drain-source voltage above which drain current becomes constant is known as *pinch off voltage*.

(ii) After pinch off voltage, the channel width becomes so narrow that depletion layers almost touch each other. The drain current passes through the small passage between these layers. Therefore, increase in drain current is very small with V_{DS} above pinch off voltage. Consequently, drain current remains constant.



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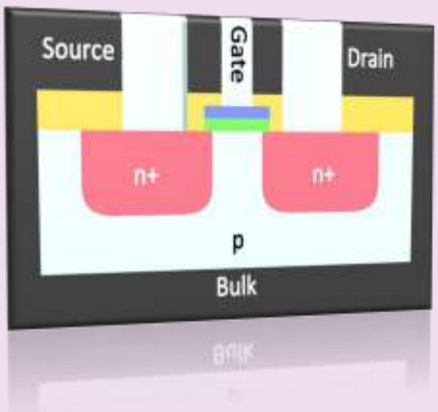

Unit 6: Field Effect Transistor (FET)

Lecture 20: Metal Oxide Semiconductor FET (MOSFET)

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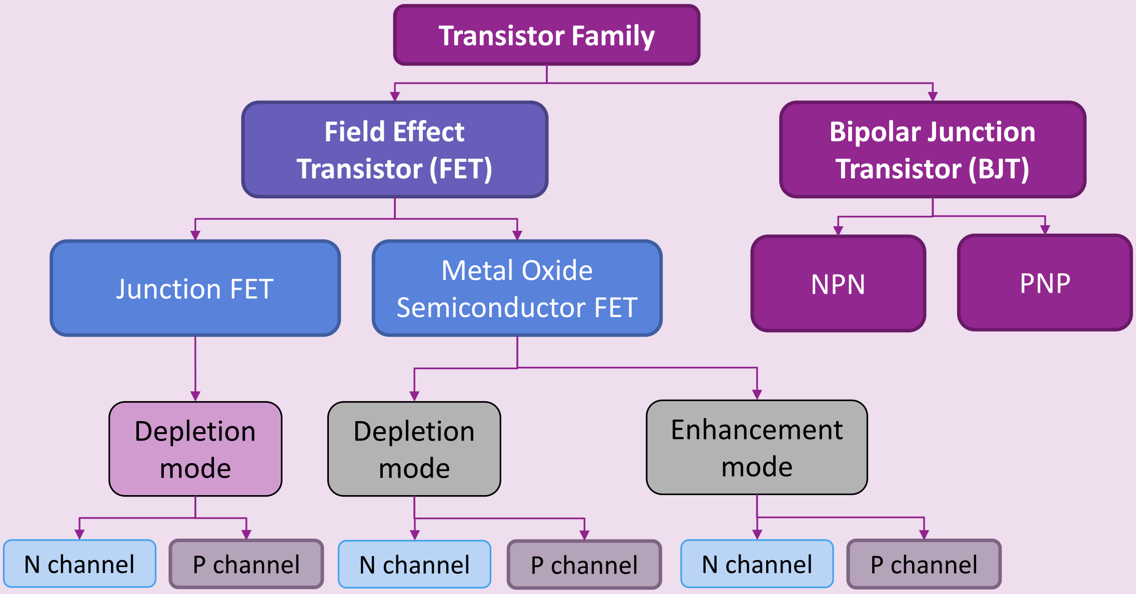
Introduction

- The **MOSFET** (**m**etal **o**xide **s**emiconductor **f**ield-**e**ffect **t**ransistor) is another category of field-effect transistor. The MOSFET, different from the JFET, has no *pn* junction structure; instead, the gate of the MOSFET is insulated from the channel by a silicon dioxide (SiO_2) layer.

- A *MOSFET* is an important semiconductor device and can be used in any of the circuits covered for *JFET*. However, a *MOSFET* has several advantages over *JFET* including high input impedance and low cost of production.



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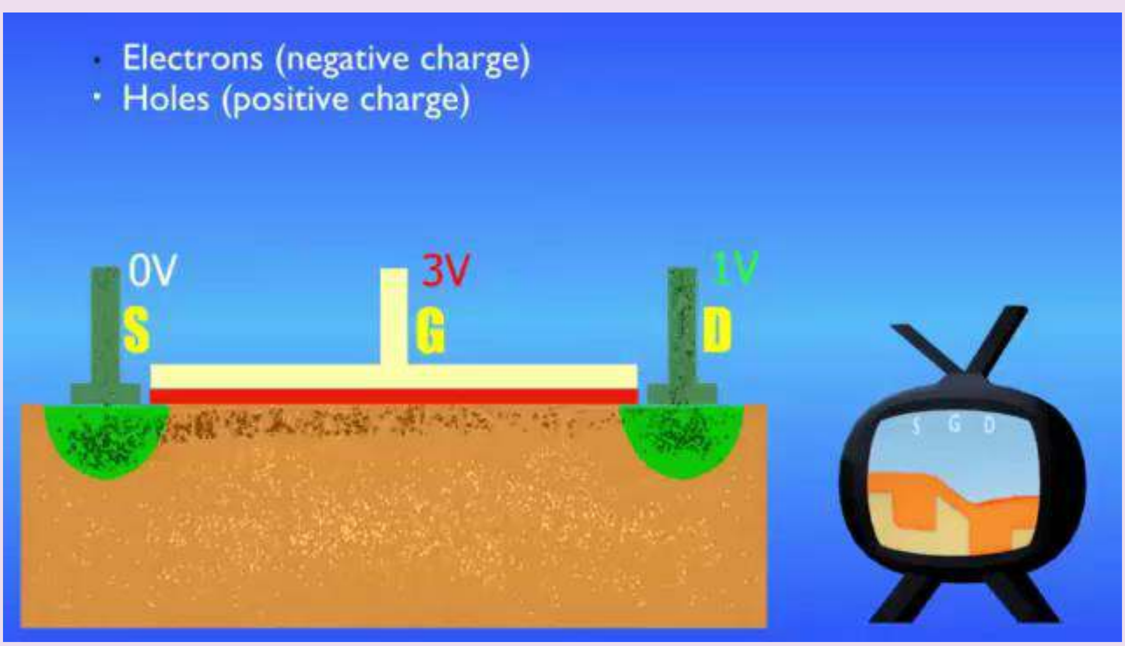

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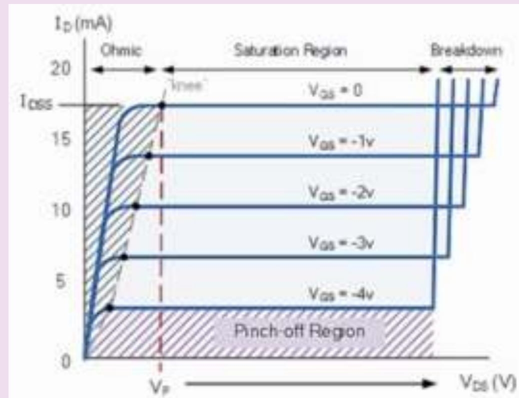
Drawback of *JFET*

- The main drawback of *JFET* is that its gate *must* be reverse biased *i.e.* it can only have negative gate operation for *n*-channel and positive gate operation for *p*-channel.
- This means that we can *only* decrease the width of the channel from its zero-bias size.
- This type of operation is referred to as *depletion-mode* operation. Therefore, a *JFET* can only be operated in the depletion-mode.



A field effect transistor (FET) that can be operated in the enhancement-mode is called a MOSFET.

Types of MOSFETs

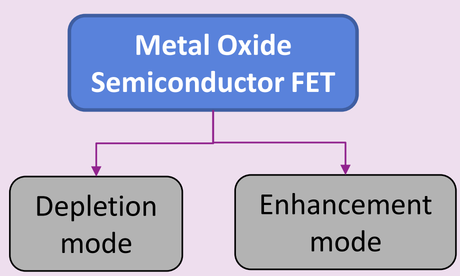
There are two basic types of *MOSFETs viz.*

1. Depletion-type *MOSFET* or ***D-MOSFET.***

The *D-MOSFET* can be operated in both the depletion-mode and the enhancement-mode. For this reason, a *D-MOSFET* is sometimes called depletion/enhancement *MOSFET*.

2. Enhancement-type *MOSFET* or ***E-MOSFET*.**

The *E-MOSFET* can be operated *only* in enhancement-mode.



The manner in which a *MOSFET* is constructed determines whether it is *D-MOSFET* or *E- MOSFET*.

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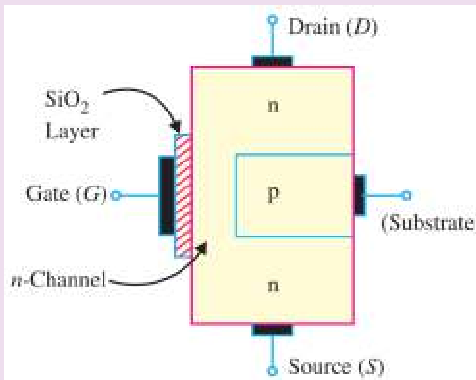
D-MOSFET

The *n*-channel *D-MOSFET* is a piece of *n*-type material with a *p*-type region (called *substrate*) on the right and an *insulated gate* on the left. The free electrons flowing from source to drain must pass through the narrow channel between the gate and the *p*-type region (*i.e.* substrate).



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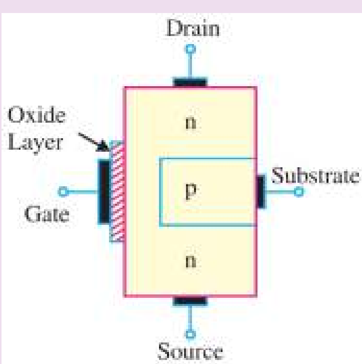
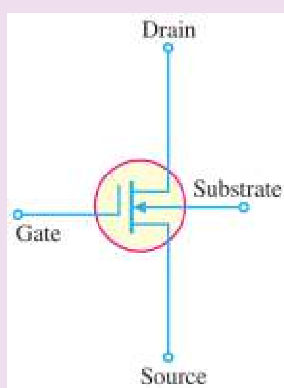
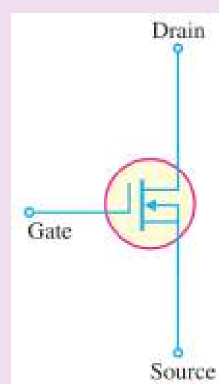
Symbols for D-MOSFET







n-channel D-MOSFET

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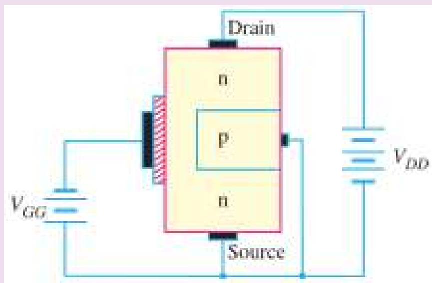
Circuit Operation of D-MOSFET

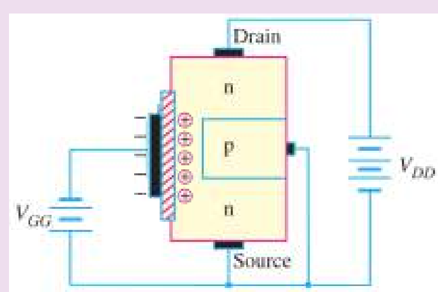
- The gate forms a small capacitor. One plate of this capacitor is the gate and the other plate is the channel with metal oxide layer as the dielectric.



- When gate voltage is changed, the electric field of the capacitor changes which in turn changes the resistance of the n-channel.
- Since the gate is insulated from the channel, we can apply either negative or positive voltage to the gate. The negative-gate operation is called *depletion mode* whereas positive-gate operation is known as *enhancement mode.*

(1) Depletion mode

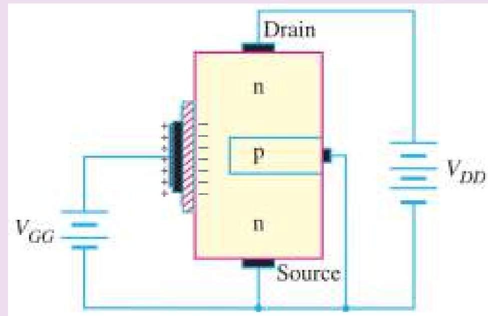
- The gate is negative.
- Electrons repel the free electrons in the *n*-channel, leaving a layer of positive ions in a part of the channel i.e. depleted the *n*-channel of some of its free electrons.
- Therefore the resistance of the channel is increased.
- By changing the negative voltage on the gate, we can vary the resistance of the *n*-channel and hence the current from source to drain.



Note: with negative voltage on the gate, the action of *D-MOSFET* is similar to *JFET*. Because the action with negative gate depends upon depleting the channel of free electrons, the negative-gate operation is called *depletion mode.*

(2) Enhancement mode

- The gate is positive.
- It induces negative charges in the *n*-channel.
- Because free electrons are added to those already in the channel, the total number of free electrons in the channel is increased.
- Thus a positive gate voltage *enhances* or *increases* the conductivity of the channel.
- By changing the positive voltage on the gate, we can change the conductivity of the channel.



Because the action with a positive gate depends upon *enhancing* the conductivity of the channel, the positive gate operation is called *enhancement mode.*

Some Remarks

(1) In a *D-MOSFET*, the source to drain current is controlled by the electric field of capacitor formed at the gate.

(2) The gate of *JFET* behaves as a reverse-biased diode whereas the gate of a *D-MOSFET* acts like a capacitor. For this reason, it is possible to operate *D-MOSFET* with positive or negative gate voltage.

(3) As the gate of *D-MOSFET* forms a capacitor, therefore, 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 1,000,000 MΩ.

(4) The extremely small dimensions of the oxide layer under the gate terminal result in a very low capacitance and the *D-MOSFET* has, therefore, a very low input capacitance. This characteristic makes the *D-MOSFET* useful in high-frequency applications.

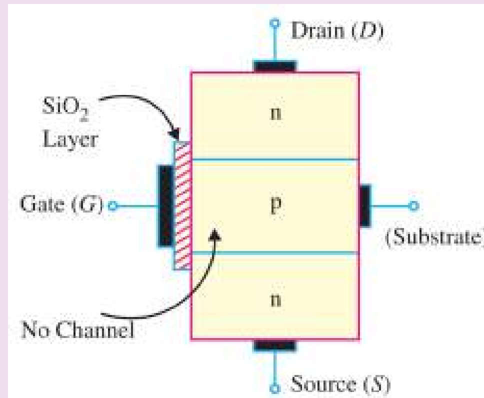
E-MOSFET

The *E-MOSFET* has no channel between source and drain unlike the *D-MOSFET*.

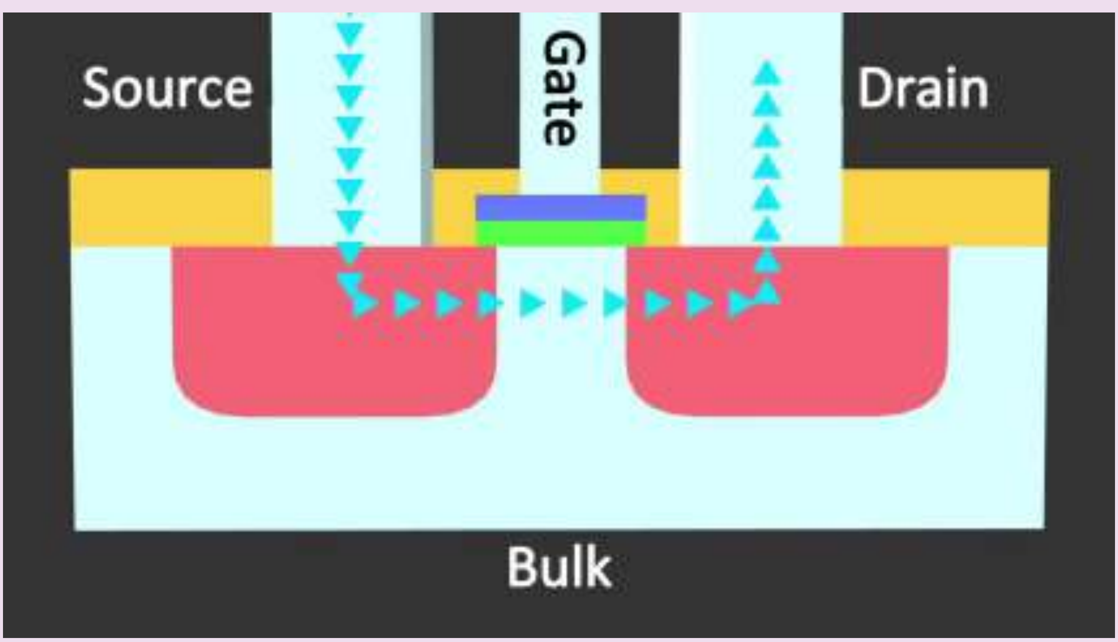
The substrate extends completely to the SiO_2 layer so that no channel exists.

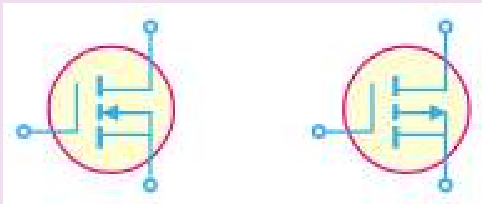
The *E-MOSFET* requires a proper gate voltage to *form* a channel (called induced channel).

It is reminded that *E-MOSFET* can be operated *only* in enhancement mode.

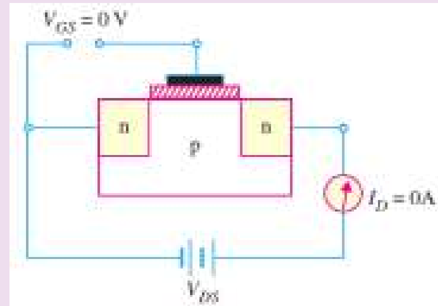


In short, the construction of *E-MOSFET* is quite similar to that of the *D-MOSFET* except for the absence of a channel between the drain and source terminals.





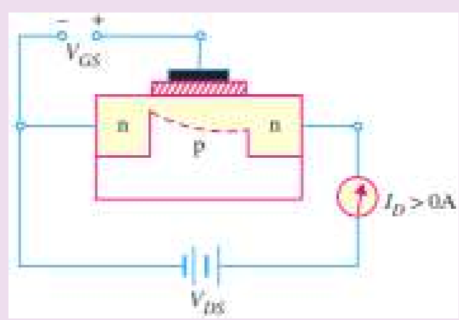
n-channel *E-MOSFET* *p*-channel *E-MOSFET*



- When V_{GS} = 0V, there is no channel connecting the source and drain.
- For this reason, *E-MOSFET* is normally *OFF* when V_{GS} = 0 V.

Note that this behavior of *E-MOSFET* is quite different from *JFET* or *D-MOSFET.*

- When gate is made positive, it attracts free electrons into the *p* region.
- The free electrons combine with the holes next to the SiO_2 layer.
- If V_{GS} is positive enough, all the holes touching the SiO_2 layer are filled and free electrons begin to flow from the source to drain.



*The minimum value of V_{GS} that turns the E-MOSFET ON is called **threshold voltage*** [$V_{GS\,(th)}$].

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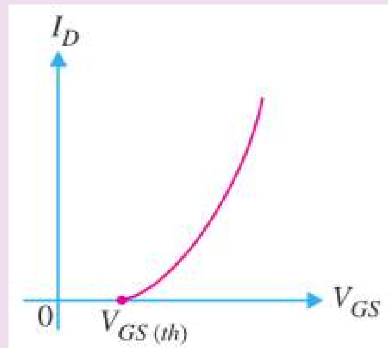
- When V_{GS} is less than $V_{GS\,(th)}$, there is no induced channel and the drain current I_D is zero.
- When V_{GS} is equal to $V_{GS\,(th)}$, the *E-MOSFET* is turned *ON* and the induced channel conducts drain current from the source to the drain.
- Beyond $V_{GS\,(th)}$, if the value of V_{GS} is *increased*, the newly formed channel becomes wider, causing I_D to increase.



The end

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