EEE 1231
Electronic Devices and Circuits

Lecture-7

Field Effect Transistors (FET)

Field Effect Transistor

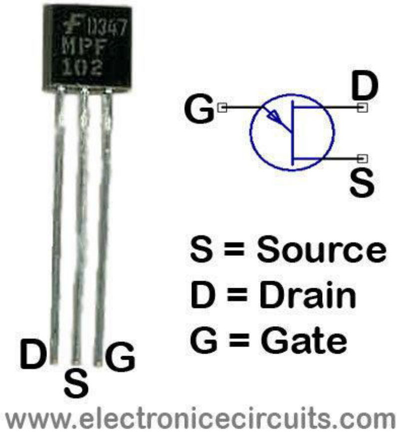
- In BJT, both holes and electrons play part in the conduction process. BJT has two principal disadvantages:
  1. It has a low input impedance because of forward biased emitter junction
  2. It has considerable noise level

- A bipolar junction transistor is a **current controlled device**, that is, output characteristics of the device are controlled by **base current** and not by base voltage.
- However, in a field effect transistor, the output characteristics are controlled **by input voltage** and not by input current. This is probably the biggest difference between BJT and FET.

Field Effect Transistor

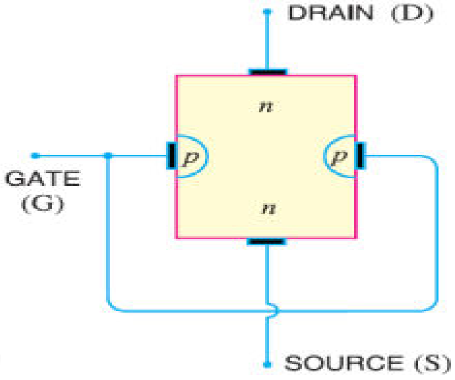
- There are two basic types of field effect transistors:
  1. Junction field effect transistor (JFET)
  2. Metal oxide semiconductor field effect transistor (MOSFET)

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

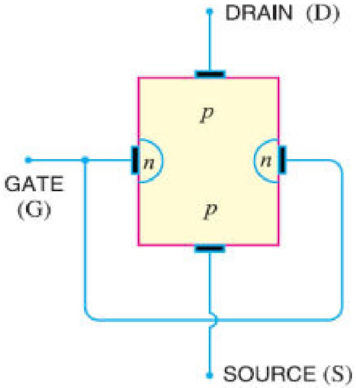


Constructional details of JFET

- A JFET consists of a p-type or n-type silicon bar containing two p-n junctions at the sides as shown in the figure. The bar forms the conducting channel for the charge carriers.
- If the bar is of n-type, it is called n-channel JFET as shown in Figure (i) and if the bar is of p-type, it is called a p-channel JFET as shown in Figure (ii).
- The two p-n 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. They are, gate (G), source (S) and drain (D).



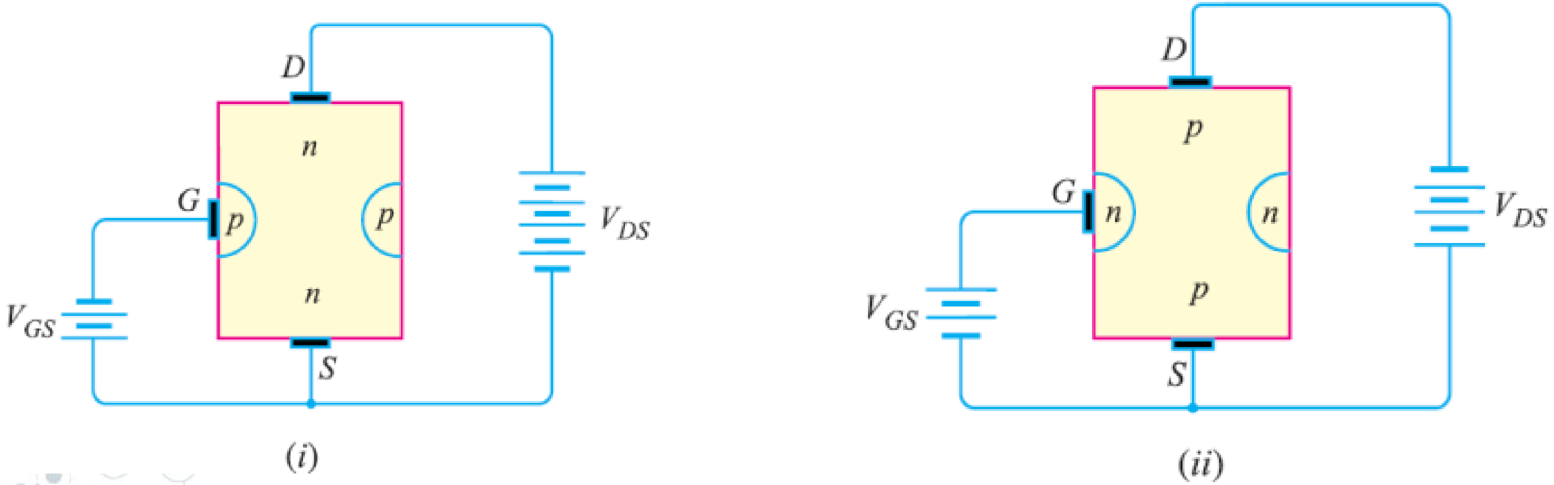
n-Channel JFET
(i)



p-Channel JFET
(ii)

JFET polarities

- Figure (i) shows n-channel JFET polarities whereas Figure (ii) shows the p-channel JFET polarities. Note that in each case, the voltage between the gate and source is such that the gate is reverse biased. This is the normal way of JFET connection. The drain and source terminals are interchangeable that is, either end can be used as source and the other end as drain.



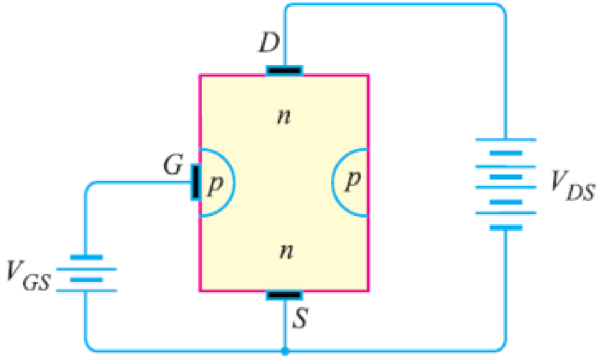
JFET polarities

◎ The following points may be noted:

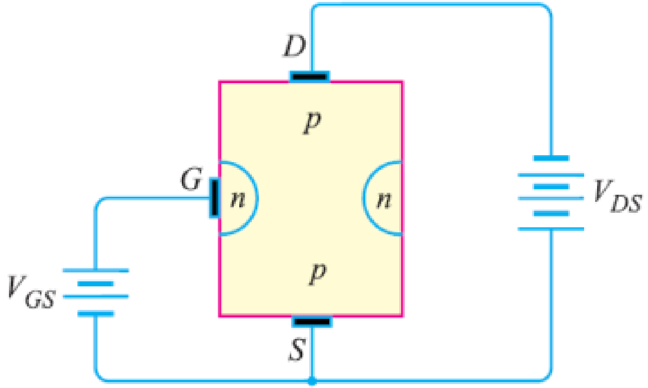
(i) The input circuit (gate to source) of a JFET is reverse biased. This means that the device has high input impedance.

(ii) The drain is so biased with respect to source that drain current ID flows from the source to drain.

(iii) In all JFETs, source current IS is equal to the drain current. That is, $I_S = I_D$.



(i)



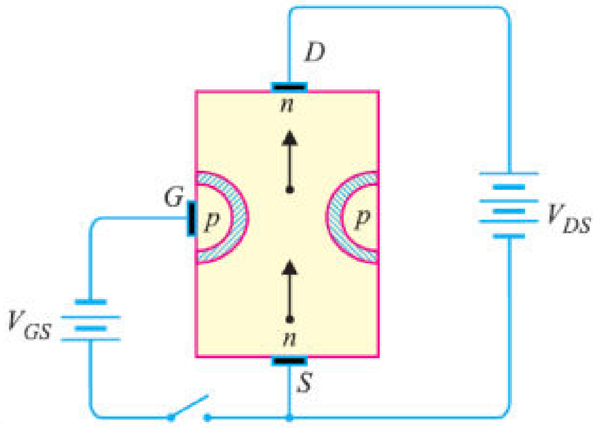
(ii)

Principle of JFET

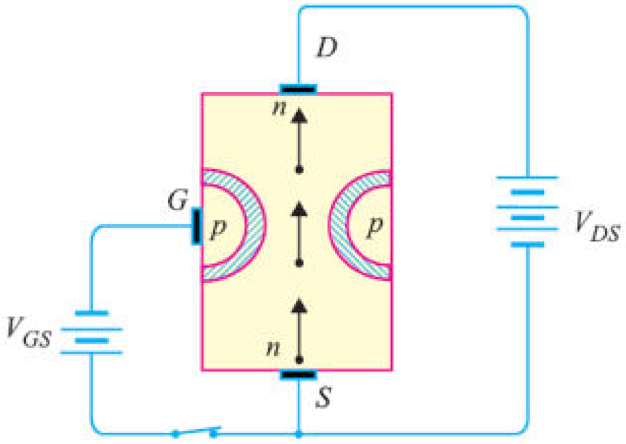
- The two p-n junctions at the sides form two depletion layers. The current conduction by **charge carriers** (free electrons in this case) is through the channel between the two depletion layers and out of the drain. The width and hence resistance of this channel can be controlled by changing the input voltage V_{GS}. The greater the reverse voltage V_{GS}, the wider will be the depletion layers and narrower will be the conducting channel.
- The narrower channel means greater resistance and hence source to drain current decreases. Reverse will happen should V_{GS} decrease.
- 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}.

Working of JFET

1. When a voltage VDS is applied between drain and source terminals and voltage on the gate is zero [Figure (i)], the two p-n junctions at the sides of the bar establish depletion layers. The electrons will flow from source to drain through a channel between the depletion layers. The size of these layers determines the width of the channel and hence the current conduction through the bar.



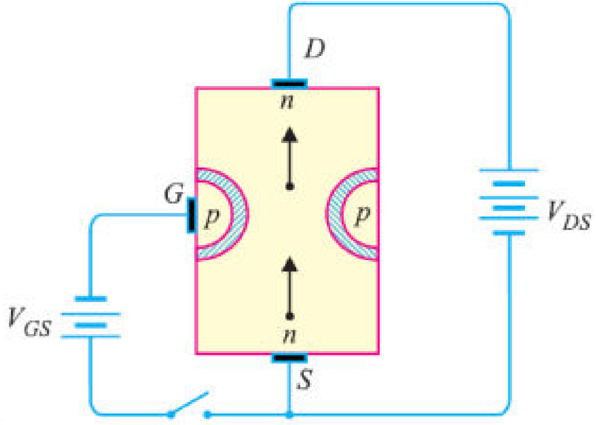
(i)



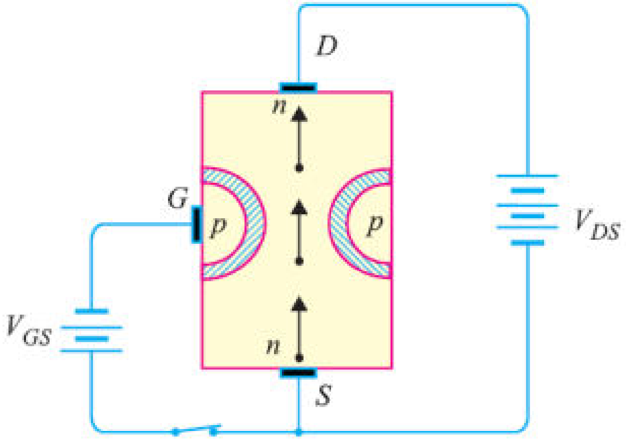
(ii)

Working of JFET

2. When a reverse voltage VGS is applied between the gate and source [Figure (ii)], the width of the depletion layers is increased. This reduces the width of conducting channel, there by increasing the resistance of n-type bar. Consequently, the current from source to drain is decreased. On the other hand, if the reverse voltage on the gate is decreased, the width of the depletion layers also decreases. This increases the width of the conducting channel and hence source to drain current.



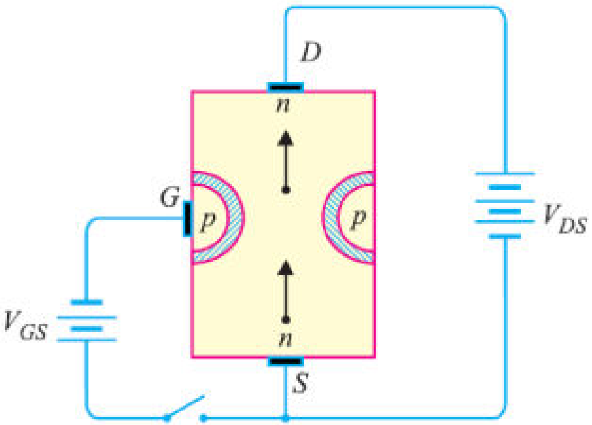
(i)



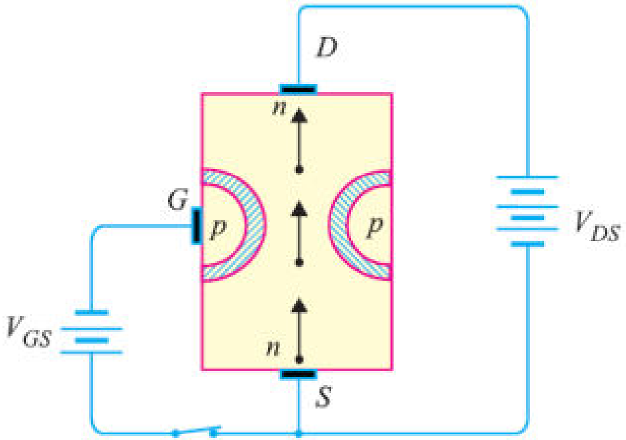
(ii)

Working of JFET

- It is clear from the above discussion that current from source to drain can be controlled by the application of potential on the gate. For this reason, the device is called field effect transistor. It may be noted that a p-channel JFET operates in the same manner as an n -channel JFET except that channel current carriers will be the holes instead of electrons and the polarities of VGS and VDS are reversed.



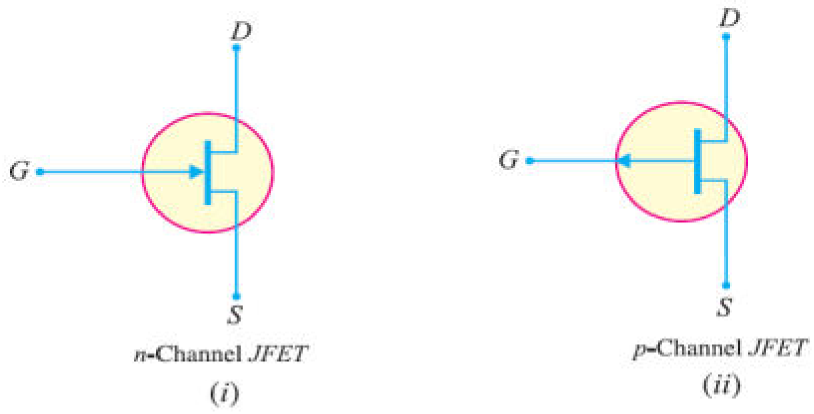
(i)



(ii)

Symbol of JFET:

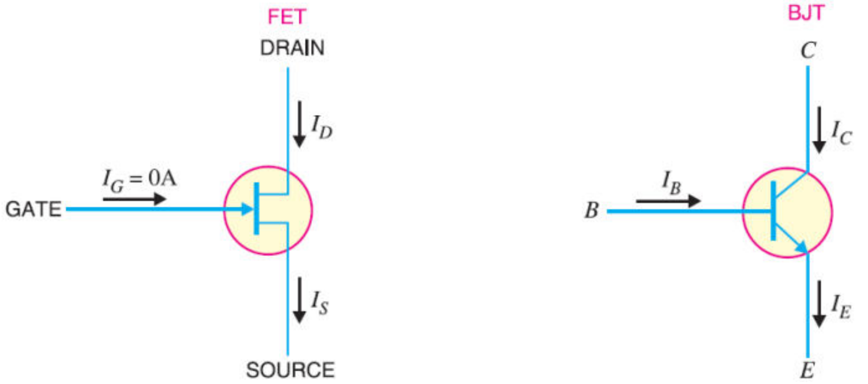
- The symbol of JFET is given below,



- The vertical line in the symbol may be thought as channel and source (S) and drain (D) connected to this line. If the channel is n-type, the arrow on the gate points towards the channel and for p-type channel, the arrow on the gate points from channel to gate

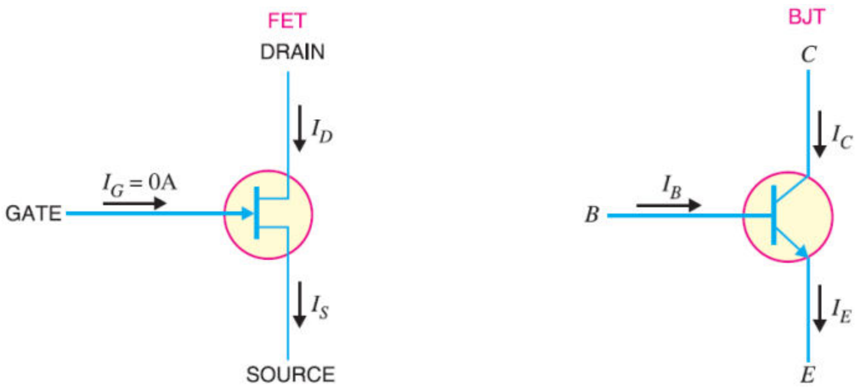
Difference Between JFET and BJT

- **(i)** In a JFET, there is only one type of carrier, holes in p-type channel and electrons in n-type channel. For this reason, it is also called a unipolar transistor. However, in an ordinary transistor, both holes and electrons play part in conduction. Therefore, an ordinary transistor is sometimes called a bipolar transistor.
  (ii) As the input circuit (gate to source) of a JFET is reverse biased, therefore, the device has high input impedance. However, the input circuit of an ordinary transistor is forward biased and hence has low input impedance.
  (iii) The primary functional difference between the JFET and the BJT is that no current (actually, a very, very small current) enters the gate of JFET (IG = 0A). However, typical BJT base current might be a few µA while JFET gate current a thousand times smaller.



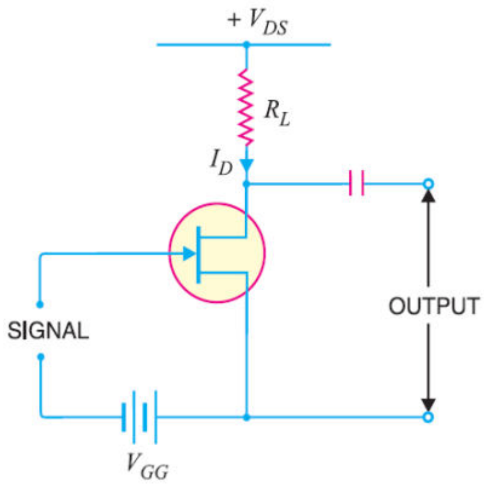
Difference Between JFET and BJT

- **(iv)** A bipolar transistor uses a current into its base to control a large current between collector and emitter whereas a JFET uses voltage on the 'gate' (= base) terminal to control the current between drain (= collector) and source (= emitter). Thus a bipolar transistor gain is characterized by current gain whereas the JFET gain is characterized as a transconductance that is, the ratio of change in output current (drain current) to the input (gate) voltage.
  (v) In JFET, there are no junctions as in an ordinary transistor. The conduction is through an n-type or p-type semi-conductor material. For this reason, noise level in JFET is very small.



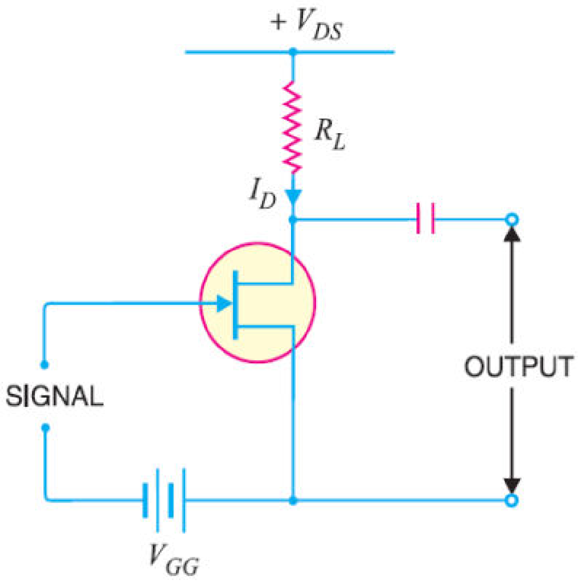
JFET as an Amplifier

- In JFET amplifier circuit, 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, the gate must be negative with respect to source, that is, input circuit should always be reverse biased. This is achieved either by inserting a battery V_{GG} in the gate circuit or by a circuit known as biasing circuit.
- In the present case, we are providing biasing by the battery V_{GG}. A small change in the reverse bias on the gate produces a large change in drain current. This fact makes JFET capable of raising the strength of a weak signal.



JFET as an Amplifier

- 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 RL. In this way, JFET acts as an amplifier.



JFET Connections

There are three leads in a *JFET viz.*, source, gate and drain terminals. However, when *JFET* is to be connected in a circuit, we require four terminals ; two for the input and two for the output. This difficulty is overcome by making one terminal of the *JFET* common to both input and output terminals. Accordingly, a *JFET* can be connected in a circuit in the following three ways :

(*i*) Common source connection (*ii*) Common gate connection

(*iii*) Common drain connection

The common source connection is the most widely used arrangement. It is because this connection provides high input impedance, good voltage gain and a moderate output impedance. However, the circuit produces a phase reversal *i.e.*, output signal is 180° out of phase with the input signal. Fig. 19.29 shows a common source *n*-channel *JFET* amplifier. Note that source terminal is common to both input and output.

Note. A common source *JFET* amplifier is the *JFET* equivalent of common emitter amplifier. Both amplifiers have a 180° phase shift from input to output. Although the two amplifiers serve the same basic purpose, the means by which they operate are quite different.

Metal Oxide Semiconductor Field Effect Transistor (MOSFET)

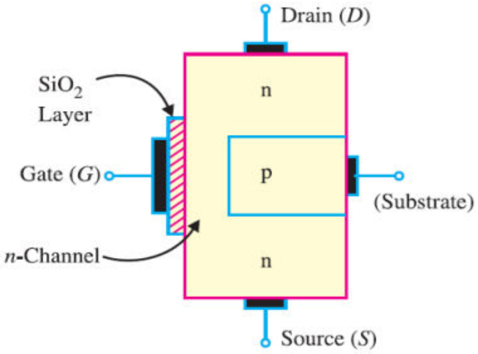
MOSFET

- 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.

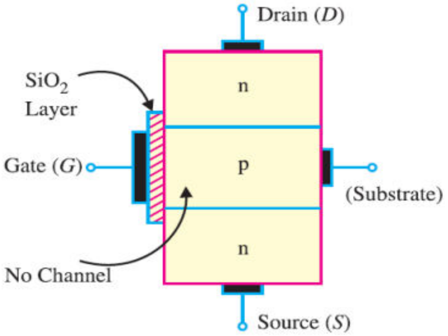
- **Types of MOSFET:**
  There are two basic types of MOSFET:
  Depletion-type MOSFET or D-MOSFET: The D-MOSFET can be operated in both the depletion mode and the enhancement mode. For this reason, a D-MOSFET is sometimes called depletion/enhancement MOSFET.
  Enhancement-type MOSFET or E-MOSFET: The E-MOSFET can be operated only in enhancement mode. The manner in which a MOSFET is constructed determines whether it is DMOSFET or EMOSFET.

D-MOSFET Construction

- The given figure shows the constructional details of n-channel D-MOSFET. It is similar to n-channel JFET except with the following modifications/remarks :
  (i) 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 as shown. The free electrons flowing from source to drain must pass through the narrow channel between the gate and the p-type region.
  (ii) Note carefully the gate construction of D-MOSFET. A thin layer of metal oxide (usually silicon dioxide, SiO2) is deposited over a small portion of the channel. A metallic gate is deposited over the oxide layer. As SiO2 is an insulator, therefore, gate is insulated from the channel. Note that the arrangement forms a capacitor. One plate of this capacitor is the gate and the other plate is the channel with SiO2 as the dielectric. Recall that we have a gate diode in a JFET.



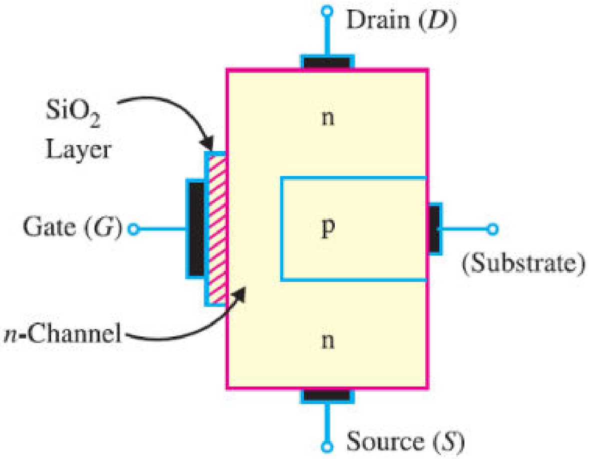
n-Channel D-MOSFET



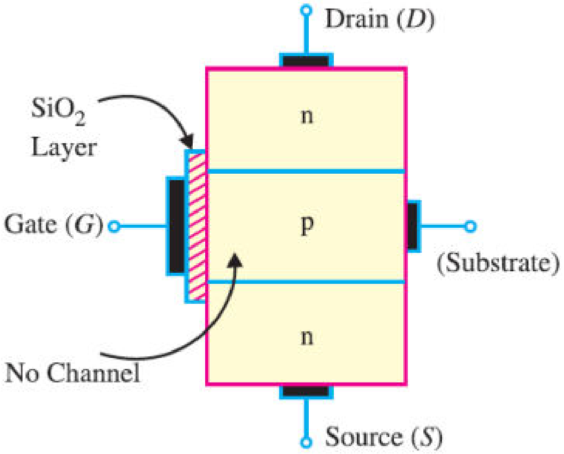
n-Channel E-MOSFET

D-MOSFET

- **(iii)** It is a usual practice to connect the substrate to the source (S) internally so that a MOSFET has three terminals, they are, source (S), gate (G) and drain (D).
  (iv) Since the gate is insulated from the channel, we can apply either negative or positive voltage to the gate. Therefore, D-MOSFET can be operated in both depletion-mode and enhancement mode.
- However, JFET can be operated only in depletion-mode.



n-Channel D-MOSFET



n-Channel E-MOSFET

E-MOSFET

- Above figure shows the constructional details of n-channel E-MOSFET. Its gate construction is similar to that of D-MOSFET. The E-MOSFET has no channel between source and drain unlike the D-MOSFET. Note that the substrate extends completely to the SiO2 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.

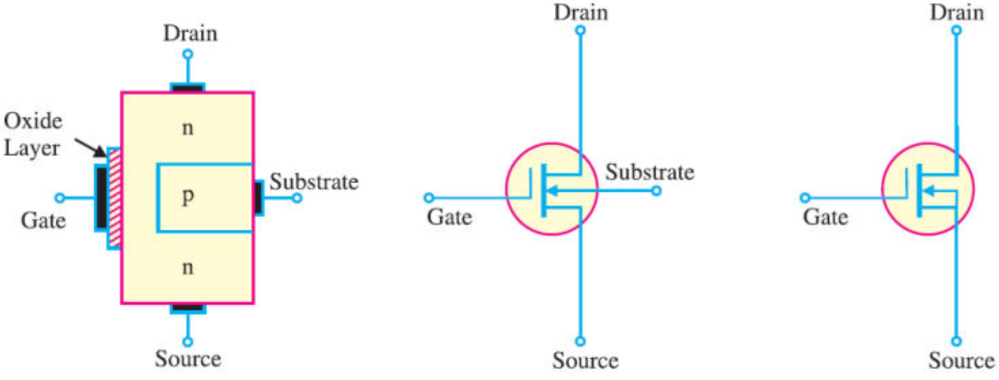
- **Symbols for D-MOSFET:**
  There are two types of D-MOSFETs. They are,
  (i) n-channel D-MOSFET.
  (ii) p-channel D-MOSFET.

E-MOSFET

Why the name MOSFET ? The reader may wonder why is the device called *MOSFET*? The answer is simple. The SiO_2 layer is an insulator. The gate terminal is made of a metal conductor. Thus, going from gate to substrate, you have a *metal oxide semiconductor* and hence the name *MOSFET*. Since the gate is insulated from the channel, the *MOSFET* is sometimes called *insulated-gate FET (IGFET)*. However, this term is rarely used in place of the term *MOSFET*.

(i) n-channel D-MOSFET

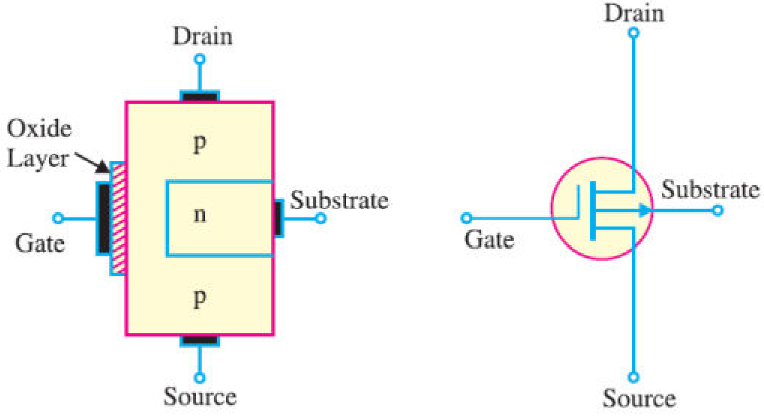
- Figure (i) shows the various parts of n-channel D-MOSFET. The p-type substrate constricts the channel between the source and drain so that only a small passage remains at the left side. Electrons flowing from source (when drain is positive with respect to source) must pass through this narrow channel. The symbol for n-channel D-MOSFET is shown in Figure (ii). The gate appears like a capacitor plate. Just to the right of the gate is a thick vertical line representing the channel. The drain lead comes out of the top of the channel and the source lead connects to the bottom. The arrow is on the substrate and points to the n-material, therefore we have n-channel DMOSFET. It is a usual practice to connect the substrate to source internally as shown in Figure (iii). This gives rise to a three-terminal device.



n-Channel D-MOSFET (*i*) Symbol (*ii*) Symbol (*iii*)

(ii) p-channel D-MOSFET

- Figure (i) shows the various parts of p-channel D-MOSFET. The n-type substrate constricts the channel between the source and drain so that only a small passage remains at the left side. The conduction takes place by the flow of holes from source to drain through this narrow channel. The symbol for p-channel D-MOSFET is shown in Figure (ii). It is a usual practice to connect the substrate to source internally. This results in a three-terminal device whose schematic symbol is shown in Figure (iii).



p-Channel D-MOSFET (*i*) Symbol (*ii*) Symbol (*iii*)

Circuit Operation of D-MOSFET

- **i) Depletion Mode:**

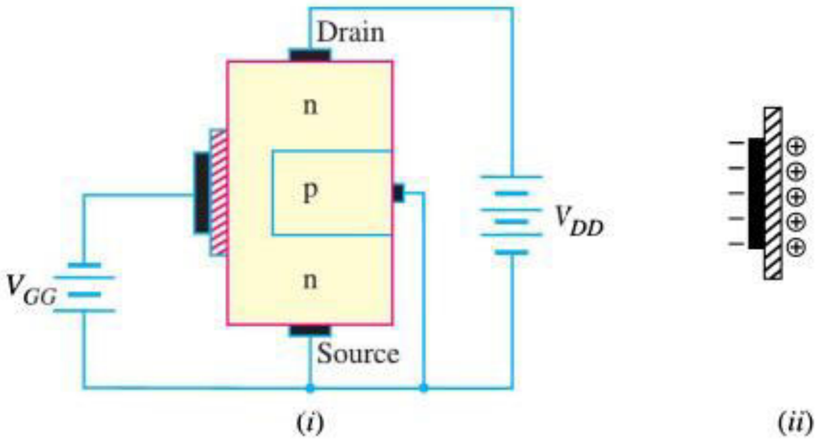


Fig. 19.47

Circuit Operation of D-MOSFET

- **ii) Enhancement Mode:**

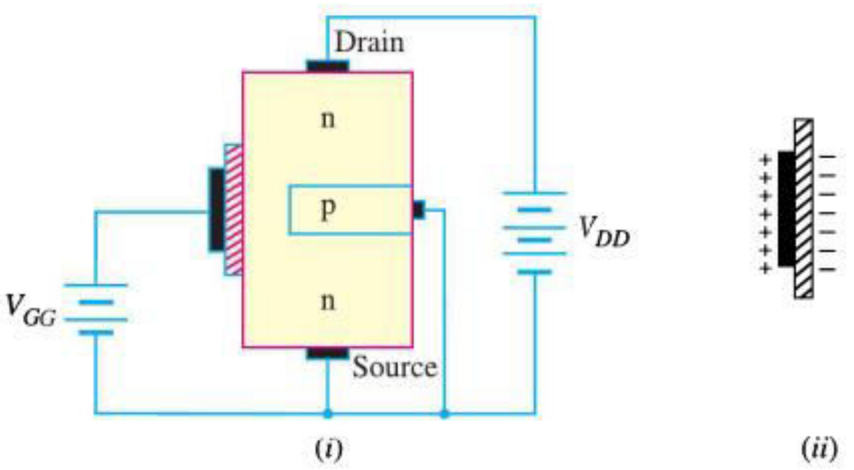
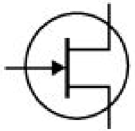
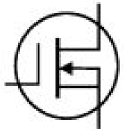
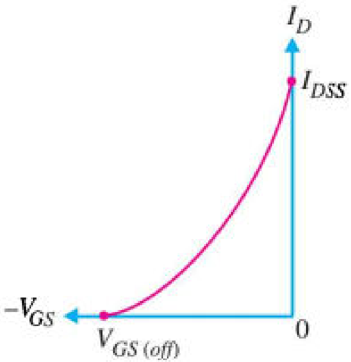
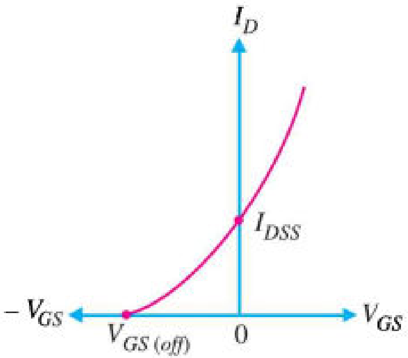


Fig. 19.48

D-MOSFETs vs JFETSs

Table below summarises many of the characteristics of *JFETs* and *D-MOSFETs*.

Devices:	*JFETs*	*D-MOSFETs*
Schematic symbol:		
Transconductance curve:		
Modes of operation:	Depletion only	Depletion and enhancement

D-MOSFETs vs JFETSs

Modes of operation:	Depletion only	Depletion and enhancement
Commonly used bias circuits:	Gate bias Self bias Voltage-divider bias	Gate bias Self bias Voltage-divider bias Zero bias
Advantages:	Extremely high input impedance.	Higher input impedance than a comparable *JFET*. Can operate in both modes (depletion and enhancement).
Disadvantages:	Bias instability. Can operate only in the depletion mode.	Bias instability. More sensitive to changes in temperature than the *JFET*.

Circuit Operation of E-MOSFET

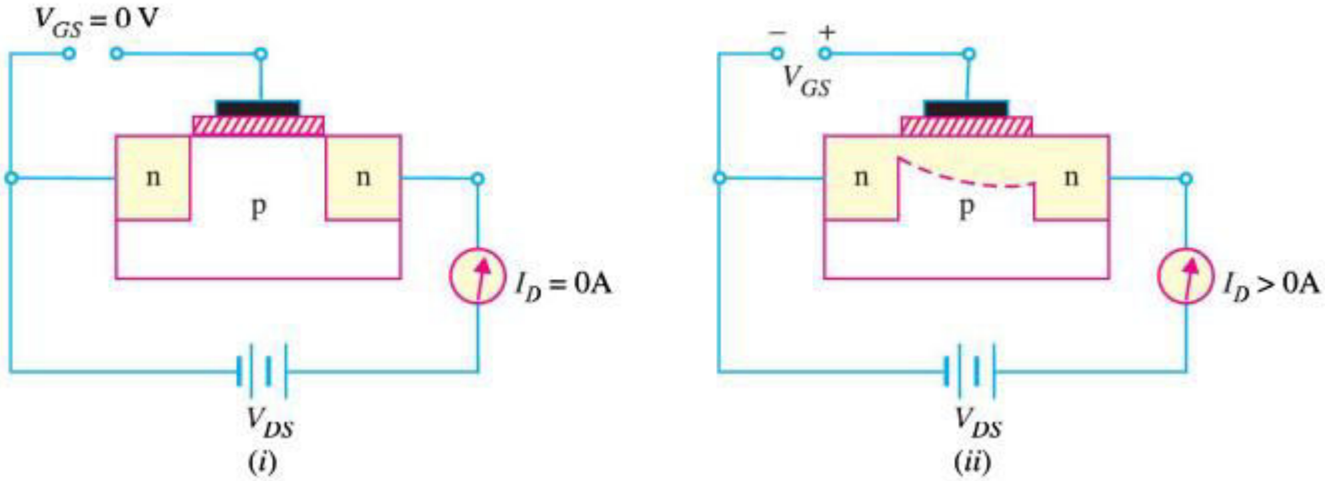
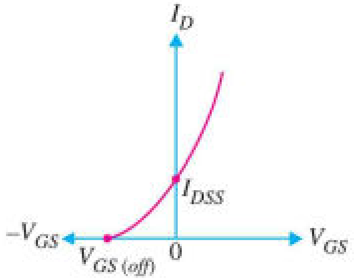
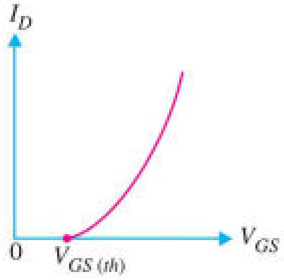


Fig. 19.55

D-MOSFETs vs E-MOSFETs

Table below summarises many of the characteristics of *D-MOSFETs* and *E-MOSFETs*

Devices:	*D-MOSFETs*	*E-MOSFETs*
Schematic symbol:		
Transconductance curve:		
Modes of operation:	Depletion and enhancement.	Enhancement only.
Commonly used bias circuits:	Gate bias Self bias Voltage-divider bias Zero bias	Gate bias Voltage-divider bias Drain-feedback bias