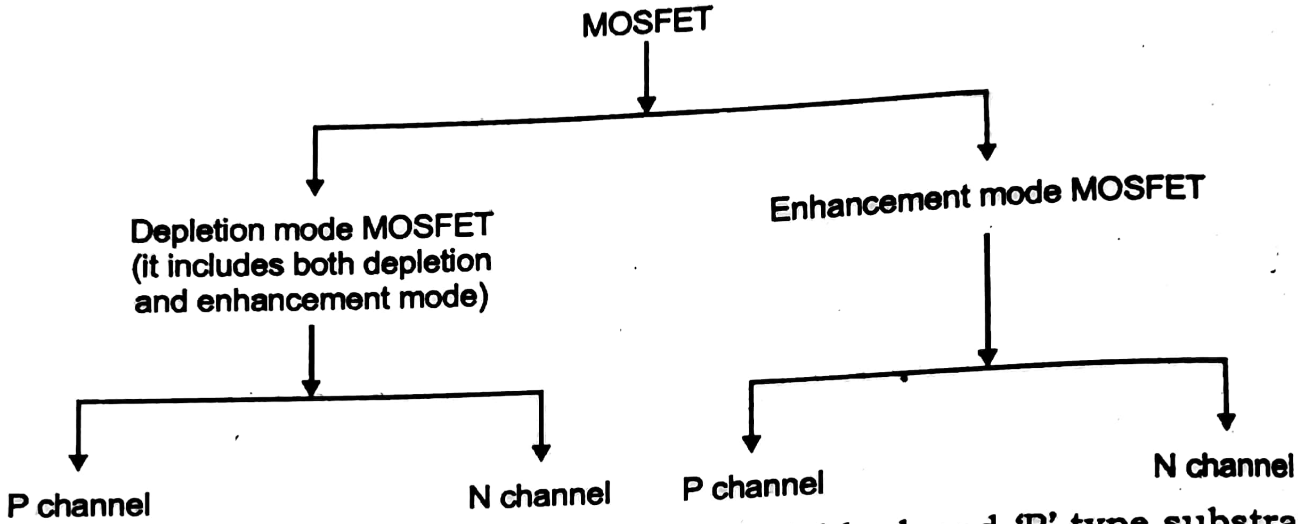
4.10 MOSFETS

- The MOSFET is a abbreviation of Metal Oxide Semiconductor Field Effect Transistor. Like JFET, it has a source, gate and drain. It is also called as IGFET (Insulated gate field effect transistor) because MOSFET is insulated from the channel. Basically the MOSFETs are of a two types namely **"Depletion type MOSFET"** and **"Enhance-type MOSFET"**.



- The N channel MOSFET consists of a highly doped 'P' type substrate into which two highly doped 'N' regions are diffused as shown in figure 4.36. These 'N' regions which will acts as source and drain.
- A thin layer of insulating silicon dioxide (SiO2) is grown over the surface of the structure and free electrons are cut into the oxide layer, allowing to move between source and drain.
- The metal area is overlaid on the entire oxide layer, similarly metal contacts are made to source and drain as shown in figure 4.36.

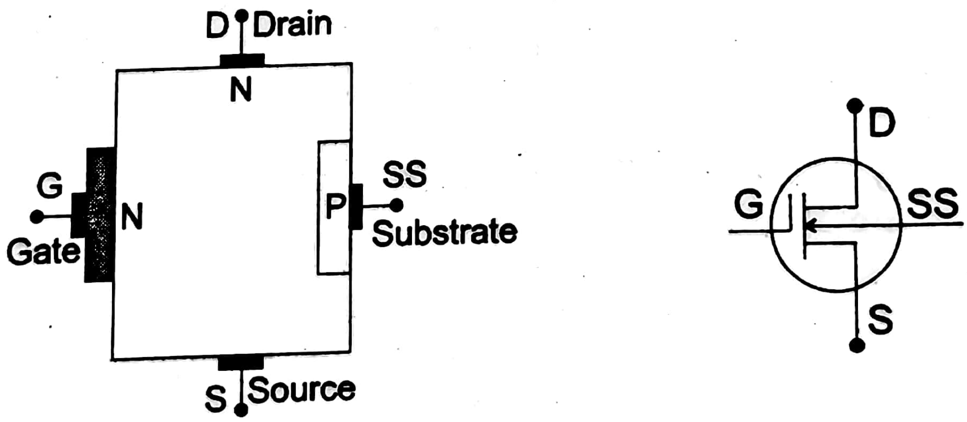


Figure 4.36

The metal area of the gate, in conjugation with the insulating dielectric oxide layer and the semiconductor channel form a parallel plate capacitor.

The SiO_2 layer insulates the gate from the channel due to which a negligible gate current flows even if the biasing is applied to gate. It causes no PN junction is existing in MOSFET like JFET thus it is also known as Insulated Gate Field Effect Transistor (IGFET).

The difference between the JFET and MOSFET are

i) MOSFET has only one P region which is called substrate, i.e., there is no PN junction like JFET.

ii) The gate is insulated from the conducting channel by metal oxide insulating film, so it is also called as Insulated gate FET.

iii) In case of MOSFET both positive and negative voltages can be applied on the gate as it is insulated from the channel for negative bias voltage it acts as depletion MOSFET. While with positive gate bias it acts as an enhancement MOSFET.

iv) Gate and channel form a parallel plate capacitor in the MOSFET assume the silicon dioxide acts as dielectric.

4.10.1 Depletion Mode MOSFET

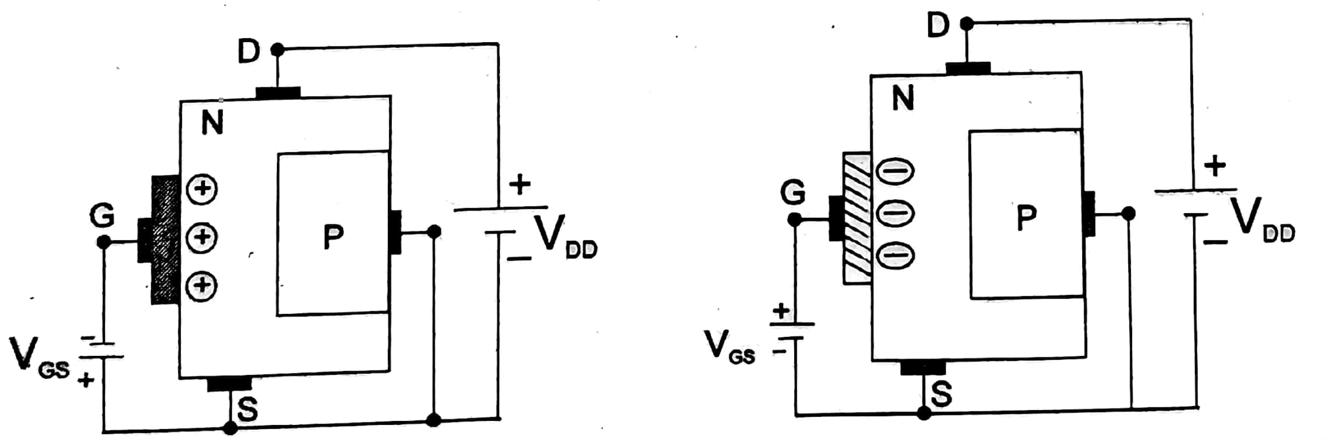
The depletion type MOSFET can be operated in two different models as given below.

a. **Depletion Mode :** The device operates in this mode, when the gate voltage is negative.

b. **Enchancement mode :** The device operates in this mode, when the gate voltage is positive.

a) Depletion mode

- Figure 4.37 shows a MOSFET with a negative gate to source voltage. When $V_{GS} = 0$ a significant current flows for a given V_{DS} like FET.



(a) Depletion mode of MOSFET *(b) Enhancement mode of MOSFET*

Figure 4.37

- When negative voltage is applied on the gate, electrons accumulate on it. If one plate of capacitor (gate) is negatively charged, induces a positive charge in the other plate (channel). Because of this, free electrons in the vicinity of positive charges are repelled away in the channel.

- As a result of this, the channel is depleted of free electrons passing through the channel thus the conduction between source to drain is reduced. Thus as the value of negative gate to source voltage is increased, the value of drain current decreases.
- At a sufficient negative value of gate to source voltage called $V_{GS}(off)$ the channel is totally depleted of free electrons and therefore the drain current reduces to zero. Thus with the negative gate voltage, the operation of MOSFET is similar to that of a JFET.
- The above discussion shows that negative gate voltage depletes the channel of free electron. It is due to this fact that the working of a MOSFET, with a negative gate voltage, is called depletion mode.

4.10.2 Characteristics of Depletion Mode MOSFET

i) Drain characteristics of Depletion type MOSFET

Figure 4.38 shows the drain characteristics for the N channel depletion - type MOSFET.

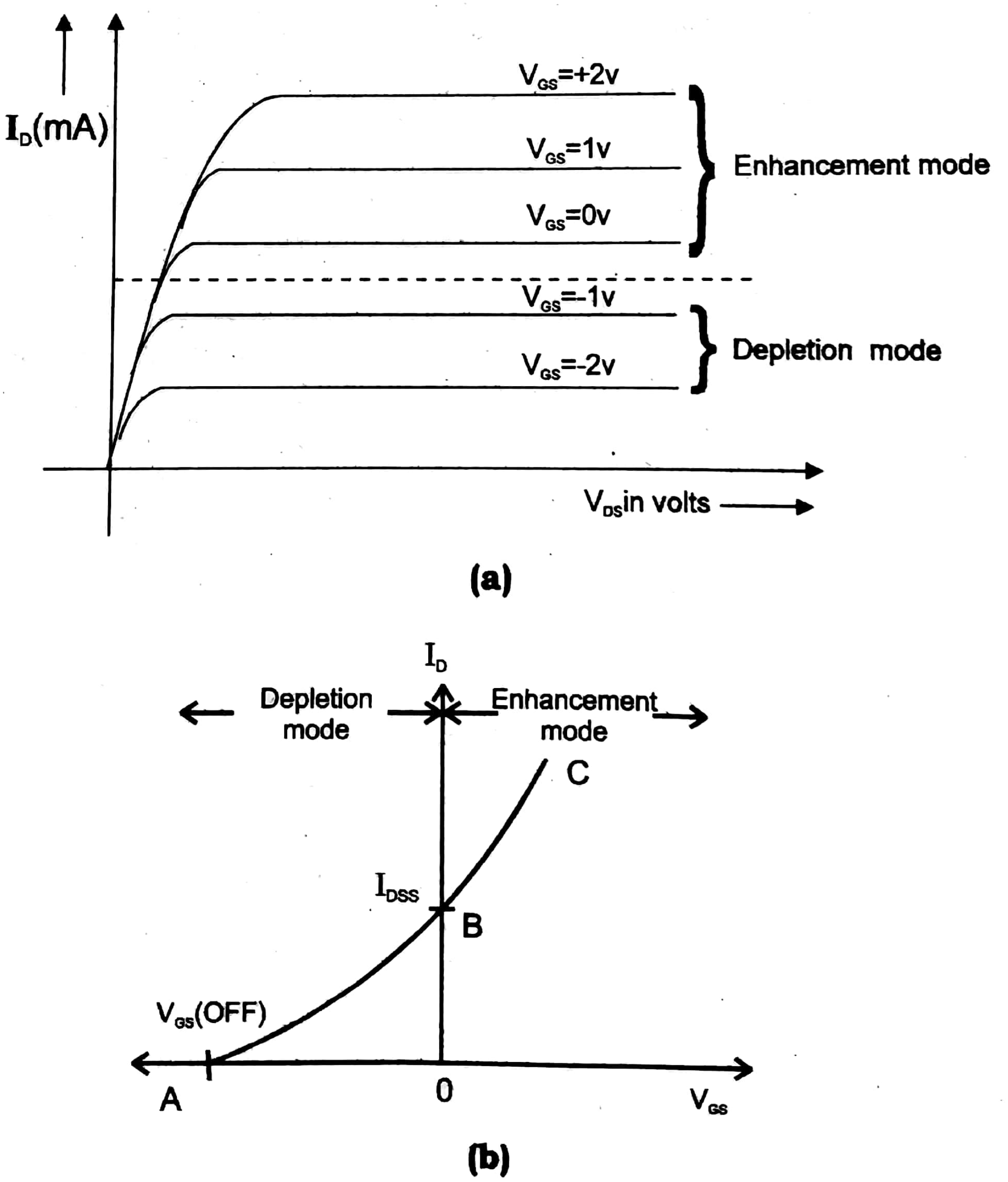


Figure 4.38

- These curves are plotted for both negative and positive values of gate to source voltage (V_{GS}). The curves shown above the $V_{GS} = 0$ have a positive value where as those below it have a negative value of VGS.
- When V_{GS} is zero and negative, the MOSFET operates in the depletion-mode. On the other hand, if V_{GS} is zero and positive, the MOSFET operates in the enhancement mode. The only difference between the JFET and the depletion MOSFET is that JFET does not operate for positive values of gate to source voltage (V_{GS}).
- When $V_{DS} = 0$, there is no conduction takes place between source to drain, if $V_{GS} < 0$, and $V_{DS} > 0$ i.e., increased above zero volt, then drain current increases linearly. As a result of $V_{GS} < 0$ is applied to the gate induces positive charged holes in the channel, and also it controls the channel width. Thus the conduction (between source to drain is maintained as constant). i.e., I_D is constant.
- If $V_{GS} > 0$ the gate induces more electrons in channel side, it is added (i.e., enhanced) with the free electron generated by source. Again the potential applied to gate determines the channel width and maintains constant current flow through it as shown in figure 4.38(a).

ii) Transfer Characteristic of Depletion-type MOSFET

Figure 4.38(b) shows the transfer characteristics for an N channel depletion type MOSFET. It may be noted from this curve, that the region AB of the characteristic is similar to that of JFET.

- This curve extends for the positive values of gate-to-source voltage V_{GS} also. The value of I_{DSS} represents the current from drain-to-source with $V_{GS} = 0$. The drain current at any point along the transfer characteristic is given by the relation,

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS}(\text{off})}\right)^2$$

It may be noted that even if $V_{GS} = 0$, the device has a drain current equal to I_{DSS}. Due to this fact it is called **normally - ON MOSFET.**

- Indepletion mode, when $V_{GS} = 0$ maximum current will flow between source to drain thus $I_D = I_{DSS}$ (refer point B) similarly, when V_{GS} increased continuously, after a certain extend the positive charges induced by gate completly depletes the channel thus no drain current i.e., $V_{GS} = V_P$ (refer point A).
- In enhancement mode of increasing VGS > 0 more free electrons are induced in the channel, thus it enhances the electron result in which I_D increases as shown in figure 4.38.

4.10.3 Enhancement Mode MOSFET

Figure 4.37(b) shows a MOSFET with a positive gate to source voltage. The positive gate voltage increases the number of free electrons passing through the channel. The greater the gate voltage, the greater is the number of free electrons passing through the channel. This increases i.e, enchances the conduction of the channel. This, positive gate voltage operation is called enchancement mode of MOSFET.

Enhancement - Only MOSFET

The enhancement type MOSFET has no depletion mode and it operates only in enhancement mode. It differs in construction from the depletion type MOSFET in the sense that it has no physical channel.

Figure 4.39 shows the basic structure of the N channel enchancement - type MOSFET. It may be noted that, the P type substrate extends the silicon dioxide layer completely as shown in figure 4.39.

It must be noted that this MOSFET is always operated with the positive gate to source voltage (V_{GS}). When gate to source voltage is zero, the V_{DD} supply tries to force free electrons from source to drain.

But the presence of P region does not permit the electrons to pass through it. Thus, there is no drain current for $V_{GS} = 0$. Due to this fact, the enhancement type MOSFET is also called normally OFF MOSFET.

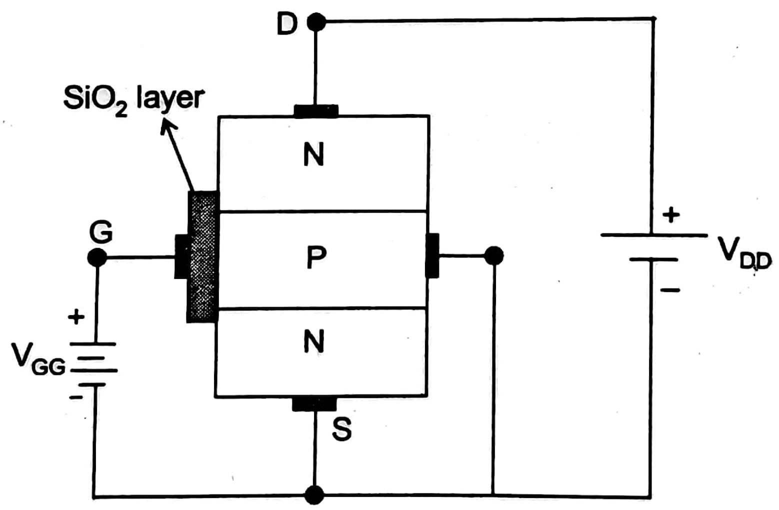


Figure 4.39

If some positive voltage is applied to the gate, it induces a negative charge in the P type substrate just adjacent to the silicon dioxide layer. The induced negative charge produced which would attracting the free electrons from the source.

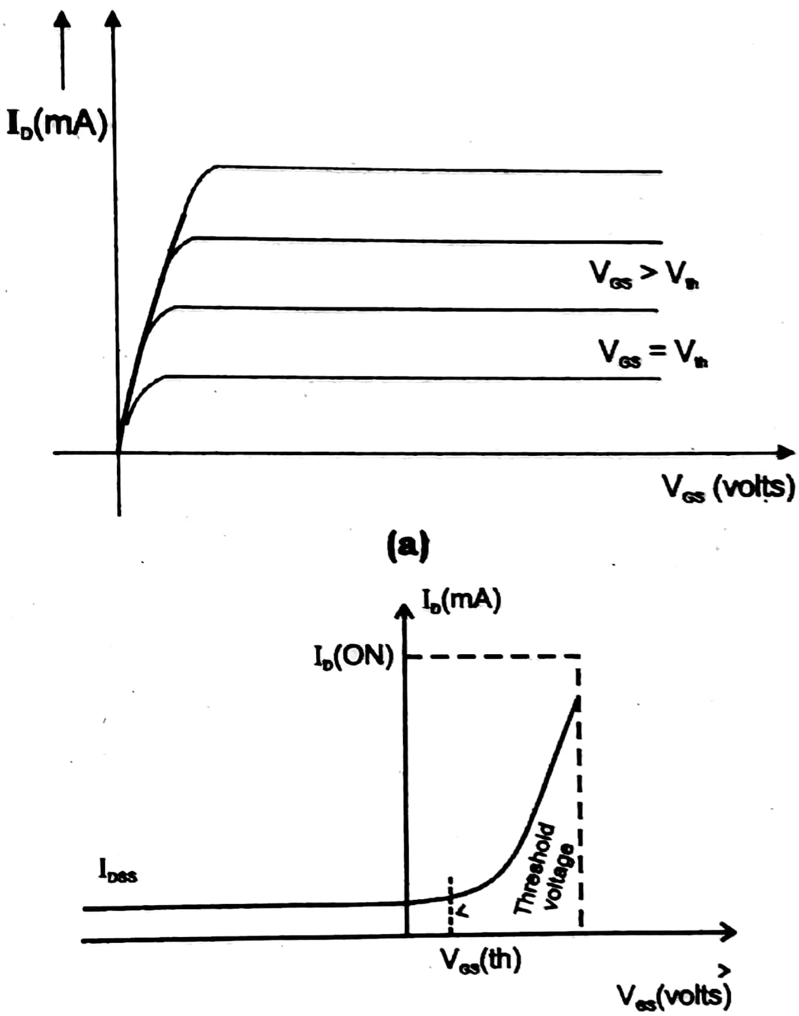
When the gate is positive enough it can attract a number of free electrons. This forms a thin layer of electrons, which stretches from source to drain. This effect is equivalent to producing a thin layer of N type channel in the P type substrate. This layer of free electrons is called N type **inversion layer.**

The minimum gate to source voltage (V_{GS}), which produces inversion layer is called "threshold voltage" and is designated by the symbol $V_{GS}(th)$. When the voltage V_{GS} is less than $V_{GS}(th)$, no current flows from drain to source. However, when the voltage V_{GS} is greater than $V_{GS}(th)$, the inversion layer connects the drain and source and we get significant values of current.

4.10.4 Characteristics of Enhancement - Only MOSFET

i) Drain characteristics

The drain characteristics for N- channel enhancement- type MOSFET is shown in figure 4.40(a). It may be noted from this figure 4.40(b), that the gate-to-source voltage (V_{GS}) is less than threshold voltage, $V_{GS}(th)$, there is no drain current.



(b)

Figure 4.40

However, in actual practice, an extremly small value of drain current does flow through the MOSFET. This current flow is due to the presence of thermally generated electrons in the P type substrate. When the value of V_{GS} is kept above $V_{GS}(th)$, a significant drain current flows.

The value of drain current increases with increase in gate to source voltage. It is because of the fact that the width of inversion layer widens for increased value of V_{GS} and therfore allows more number of free electrons to pass through it. The drain current reaches its saturation value above certain value of drain-to source voltage (V_{DS}).

ii) Transfer Characteristics for Enhancement-type MOSFET

Figure 4.40(b) shows the transfer characteristics for N-channel enhancement type MOSFET. It may be noted from this figure 4.40(b) there is no drain current when the gate-to-source voltage, $V_{GS} = 0$. However, if V_{GS} is increased above the threshold voltage, $V_{GS}(th)$, the drain current at any point along the curve is given by the relation.

$$I_D = k[V_{GS} - V_{GS}(th)]^2$$

where k is a constant, whose value depends on the type of MOSFET.

4.10.5 Comparison of JFETS and MOSFETS

JFET and MOSFETS are remarkably similar in their operating principles as well as in their electrical characteristics. However, the following are the main differences.

JFET	MOSFET
1. JFET operates only in depletion mode, because the input junction is always reverse biased. If the gate source (input junction) is forward biased excess carrier in junction enhances the conduction and the gate current is substantial and it is undesirable.	1. MOSFET operates in both enhancement and depletion method.
2. Input impedance of JFET is less because gate takes a very small leakage current.	2. MOSFET has high input impedance than JFET because the gate current is negligible.
3. Output characteristics in flatter than MOSFET, it indicates the drain resistance in high.	3. Drain resistance is less.
4. Difficult to fabricate than MOSFET.	4. Easier to fabricate.
5. PN junction formed between gate and channel.	5. There is no PN junction, due to the SiO_2 layer between gate and channel it acts as capacitor.
6. JFET does not requires any additional protection circuits.	6. MOSFET get damaged easily, if they are not operated properly thus additional protective circuits are needed.