

Field-Effect Transistor (FET)

2.1 Introduction

The field effect transistor (FET) is a semiconductor device whose operation consists of controlling the flow of current through a semiconductor channel by applying an electric field (voltage). Usually, a field effect transistor (FET) is a three-terminal semiconductor device (Figures 2-1a-b), in which current conduction is via one type of charge carriers (electrons or holes). Unlike the usual transistor, the flow of current is controlled by means of an electric field (controlled by the effect of the electric field) developed between the gate electrode (g) and the conducting channel of the device.

There are two types of FETs:

- (a) Junction field effect transistors (JFET).
- (b) Metal-oxide semiconductor field effect transistor (MOSFET).

These two types of FETs will be introduced in this chapter. Both types of FETs are categorized to n-channel or p-channel depending on their constructions. Furthermore, the MOSFET type is further categorized into depletion and enhancement types.

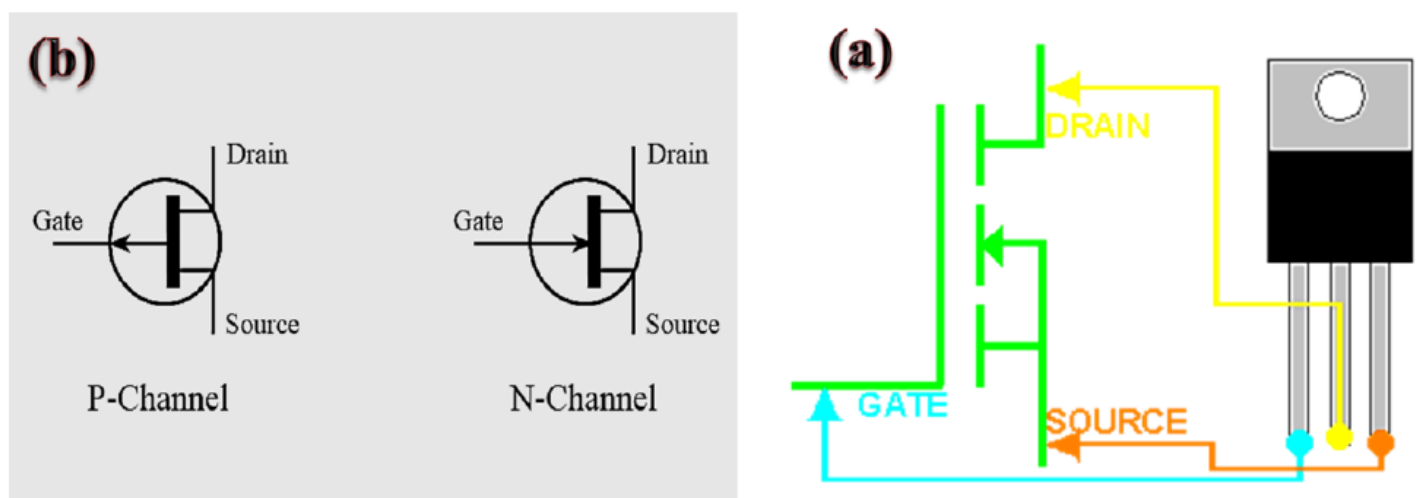
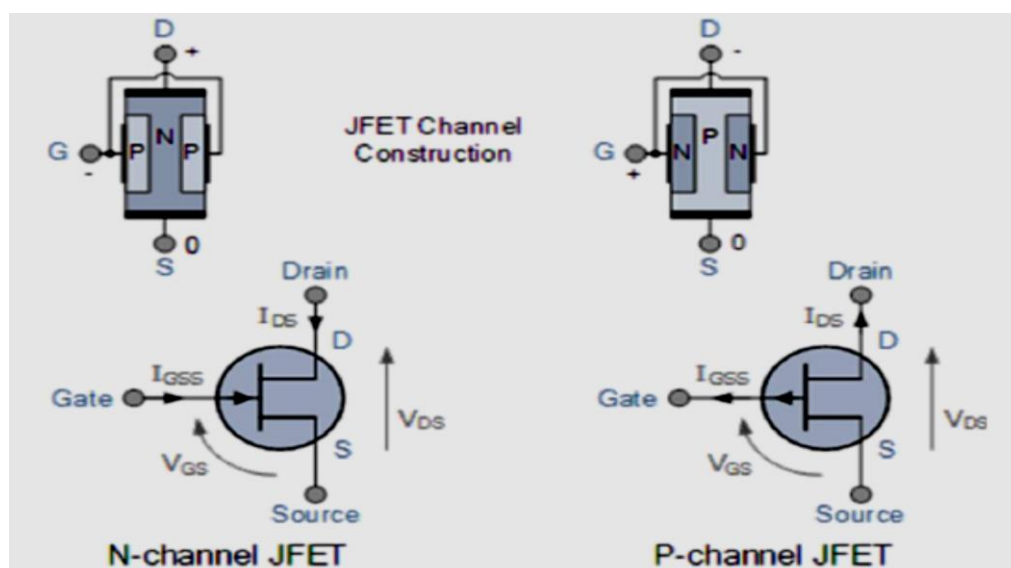


Figure (2-1a-b): Field effect transistor (FET).

2.2 Junction Field Effect Transistor (JFET) Construction

The junction field effect transistor (JFET) is a three-terminal device with one terminal capable of controlling the current between the other two. The JFET are of two types include n-channel JFET and p-channel JFET. The basic construction of n-channel (or p-channel) JFET is shown in Fig (2-2). Generally n-channel JFET is preferred, in an n-channel JFET consists of an n-type silicon bar with two islands of p-type semiconductors material diffused on the opposite sides of its middle part, thus forming two p-n junctions (forming diodes). The two (p-type) regions are connected with each other (externally or internally) and are named gate (G). The ohmic contacts are made at the two ends of the n-type semiconductor bar (silicon). One terminal is known as the source (S) through which the majority carriers (electrons in this case) enter the bar. The other terminal is known as the drain (D) through which these majority carriers leave the bar. In essence, therefore, the drain and the source are connected to the ends of the n-type channel and the gate to the two layers of p-type material. Thus, a junction field effect transistor (FET) has essentially three terminals called gate (G), source(S) and drain (D).

The silicon bar works like a resistor between its two terminals D and S. The gate terminal is similar to the base of an ordinary transistor. It is used to control the flow of current from source to drain. Thus source and drain terminals are similar to emitter and collector terminals respectively of a BJT.



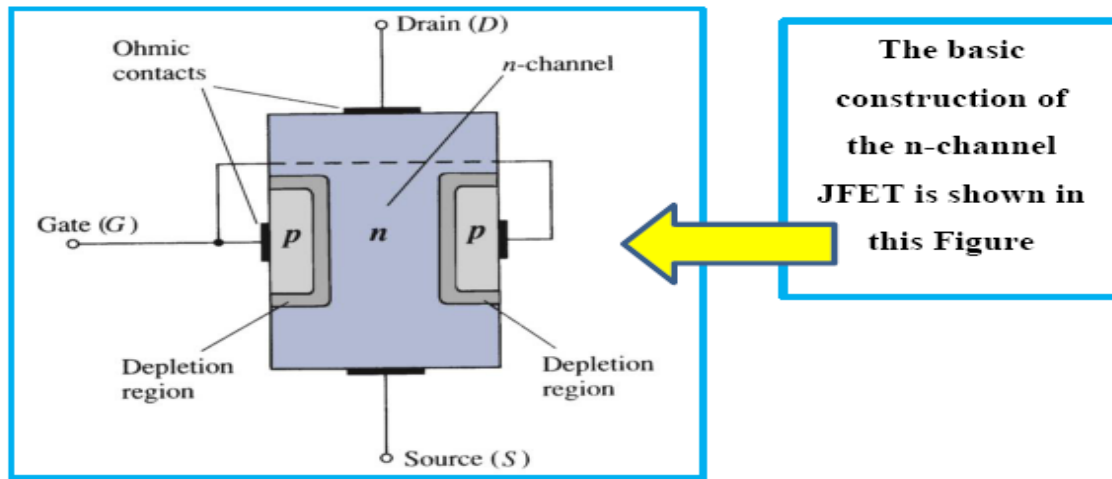


Fig. (2-2): Junction field effect transistors (JFET) (n-channel and p-channel).

2.3 Basic Operation and Characteristics of JFET

The circuit diagram of an n-channel JFET with normal polarities is shown in Fig. (2-3). When an absence of any applied potentials the JFET has two p-n junctions under no-bias conditions, the depletion regions around the p-n junctions are of equal thickness and symmetrical. In contrast, when a voltage V_{DS} is applied across the drain and source terminals and voltage applied across the gate and source (V_{GS}) is zero (i.e gate circuit is open), the two p-n junction form a very thin depletion layer. Thus, a large amount of electrons will flow from source to drain through a wide channel formed between the two depletion layers, and that means ($I_D = I_{DSS}$). Whereas, when a reverse V_{GS} ($-V_{GS}$: negative) is applied across the gate and source terminals, the width of the depletion layer is increased. This reduces the width of the conducting channel thus decreasing the conduction (flow of electrons) through it. Therefore, the current flowing from source to drain depends upon the width of the conducting channel, which depends upon the thickness of depletion layer form by the two p-n junctions depends upon the voltage applied across the gate source terminals. It is clear that the current from source to drain can be controlled by applies of potential (electric field) on the gate. That is why the device is called field effect transistor. It may be noted that a (p-channel) JFET also operates in the same method as an (n-channel) JFET except that the channel current carriers will be holes instead of electrons and all the polarities will be reversed.

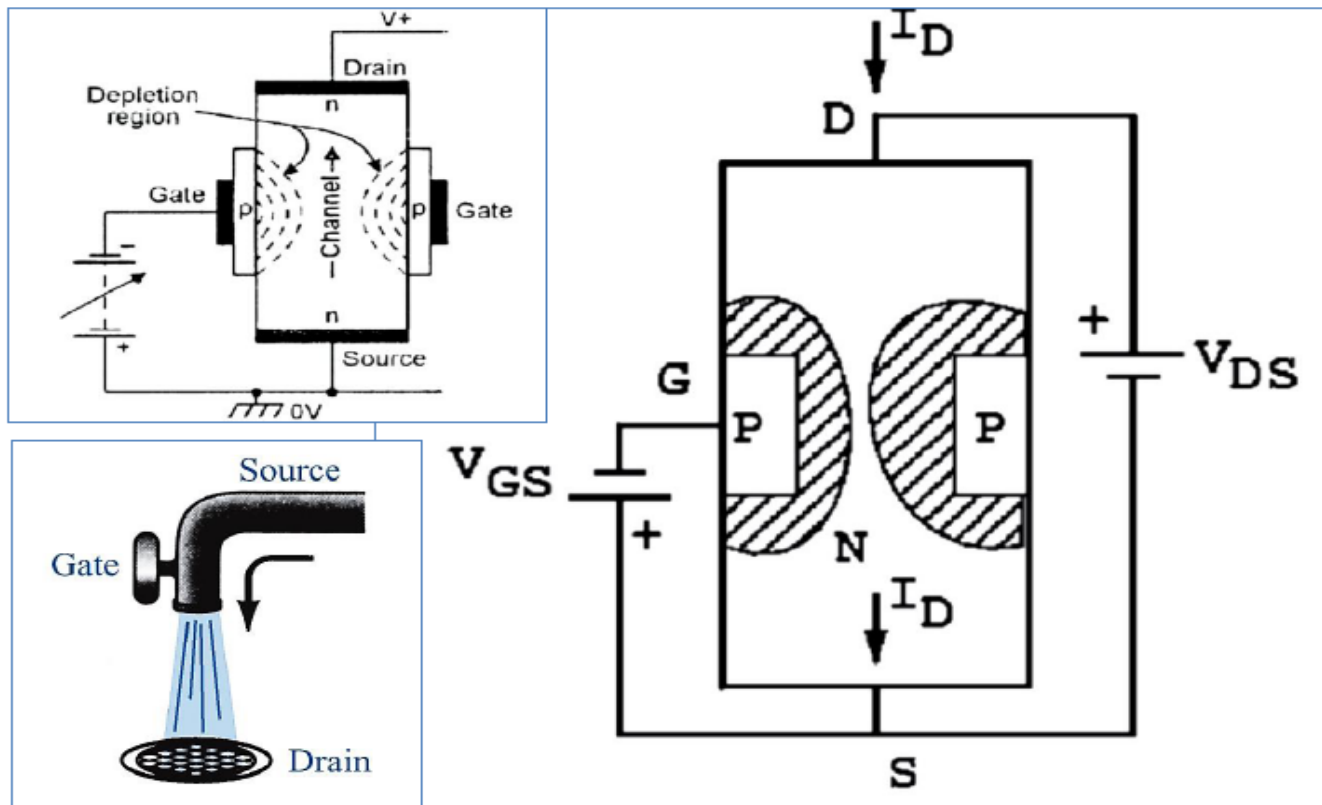


Fig. (2-3): The circuit diagram of an n- channel JFET.

Moreover, the JFET characteristics can be studied for both n-channel and p-channel. Where, the n-channel JFET characteristics or transconductance curve is showed in the Fig. (2-4) below. It is graphed between drain current (I_D) and gate-source voltage (V_{GS}). There are multiple regions in the transconductance curve and they are ohmic, saturation, cutoff, and breakdown regions.

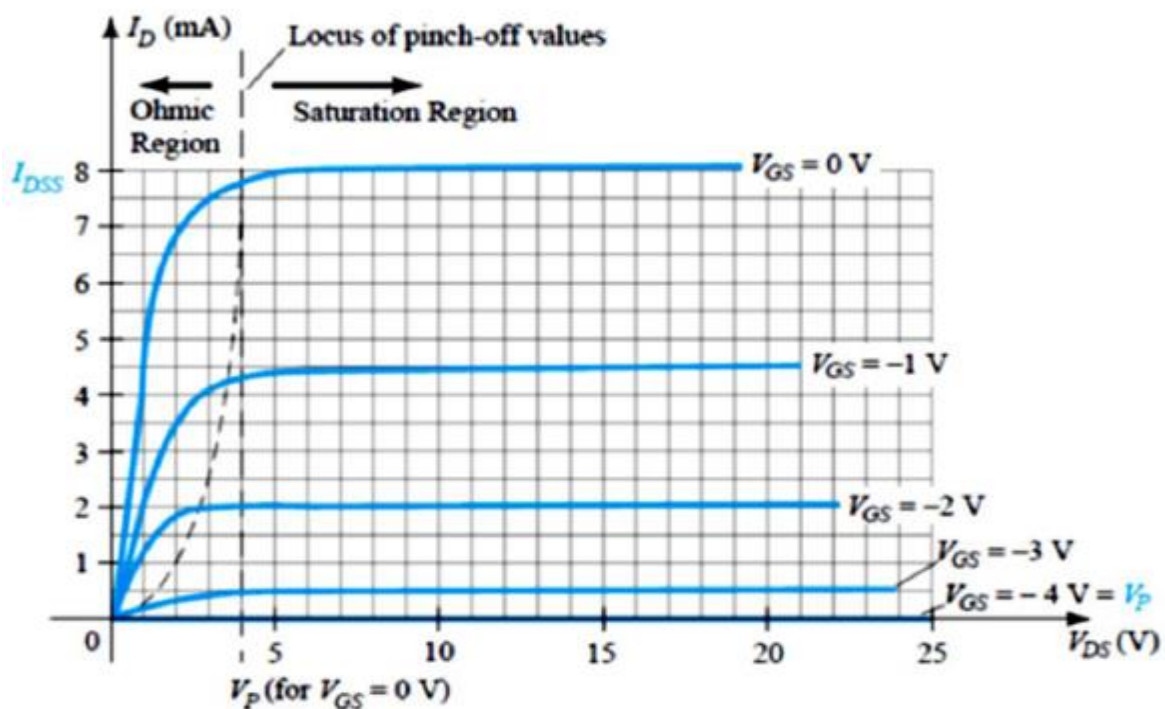


Fig. (2-4): (I-V) Characteristics of n-channel JFET, where for the n-channel device the controlling voltage V_{GS} is made more and more negative from its $V_{GS} = 0$ V level. In other words, the gate terminal will be set at lower and lower potential levels as compared to the source.

2.4 Metal Oxide Semiconductor Field Effect (MOSFET)

The Metal Oxide Semiconductor Field Effect Transistor (MOSFET) is one type of FET transistor. MOSFET is further categorized into depletion and enhancement types. Usually, the (MOSFET) is a three terminal semiconductor device. There are three terminals include source (S), gate (G) and drain (D). Unlike a JFET, in this device the gate is electrically insulated from the current carrying channel therefore sometimes it is also known as insulated gate FET (IGFET).

The gate current is very small whether the gate is positive or negative. The metal oxide semiconductor field effect transistor (MOSFET) can be used in any of the circuits covered for the FET. In present days, the MOSFET transistors are mostly used in the electronic circuit applications instead of the JFET.

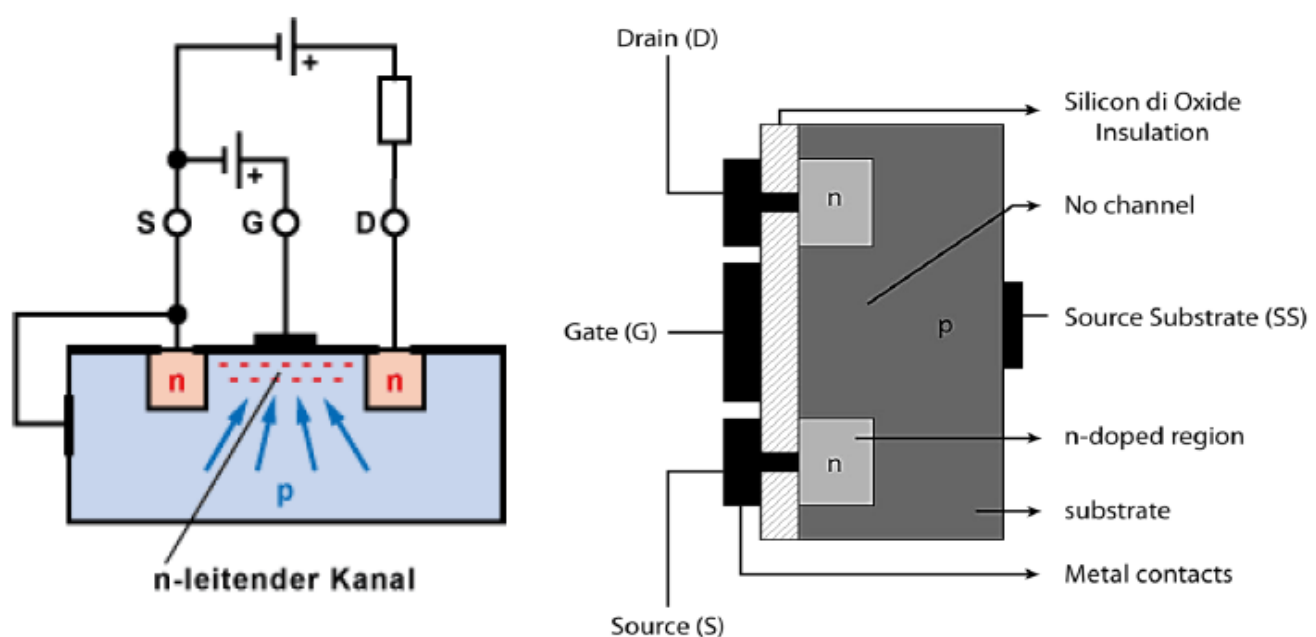


Fig. (2-5): Metal oxide semiconductor field effect transistor (MOSFET: n-channel).

2.5 Construction of MOSFET

As aforementioned, the MOSFET is basically classified into two forms they are depletion and enhancement types transistors. The MOSFET is also available in both types, n-channel (NMOS) and p-channel (PMOS) Fig. (2-6).

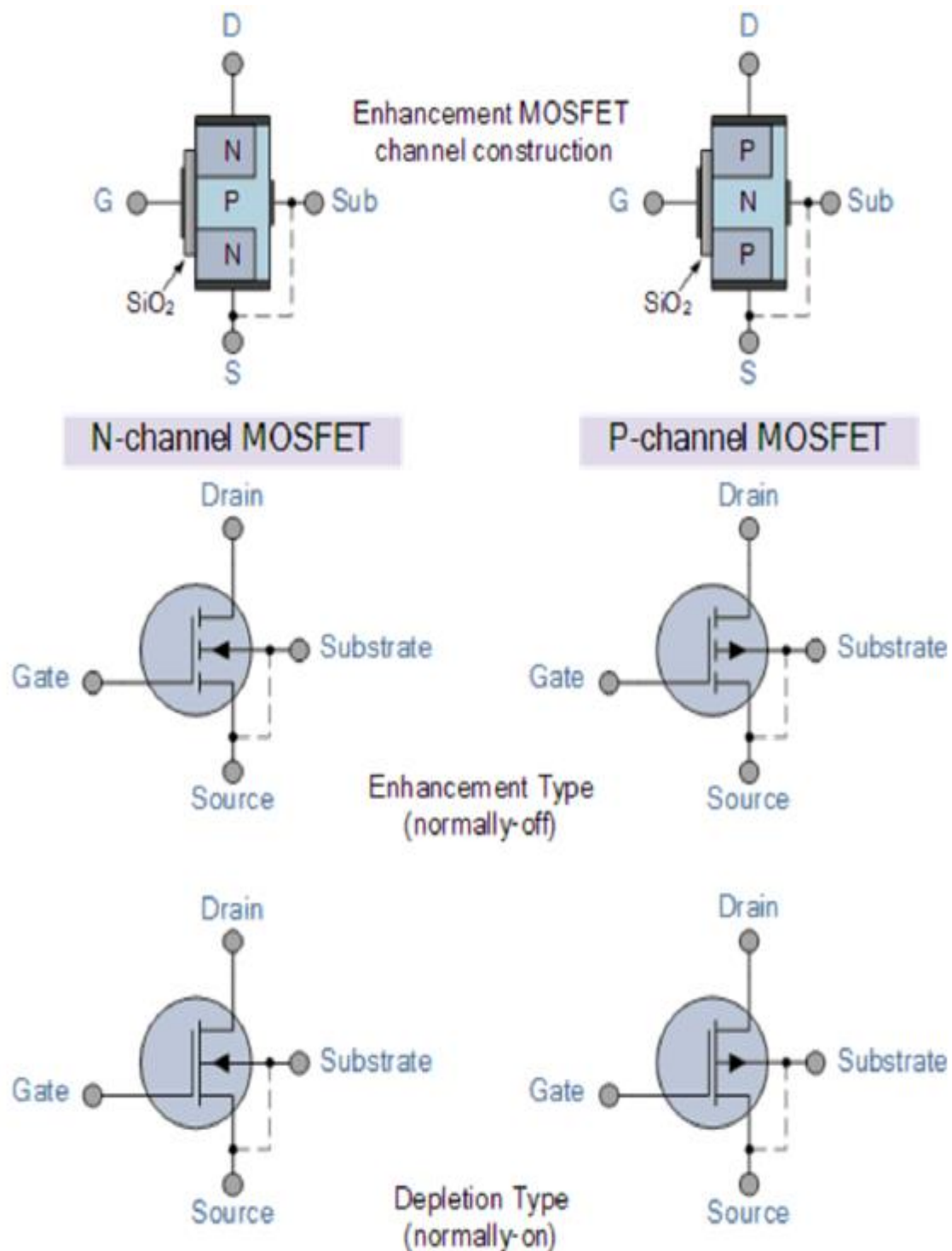


Fig. (2-6): Metal oxide semiconductor field effect transistor (MOSFET) types, n-channel (NMOS) and p-channel (PMOS)

The basic structure of the MOSFET is shown in the Figures (2-5 and 2-6). The construction of the MOSFET is very different as compared to the construction of the JFET. In both enhancement and depletion modes of MOSFETs an electric field is produced by gate voltage which changes the flow charge carriers, such as electrons for n-channel and holes for p-channel.

The simple side view of an n-channel MOSFET is shown in Fig. (2-6) left the figure shows its constructional details. The source (S) and drain (D) terminals are connected through metallic contacts to n-doped regions linked by an n-channel as shown in the Figures (2-5 and 2-6). The gate (G) is also connected to a metal contact surface but remains insulated from the n-channel by a very thin layer usually silicon dioxide SiO_2 . The fact that the deposited SiO_2 layer is an insulating layer reveals that there is no direct electrical connection between the gate (G) terminal and the channel of a MOSFET. The input impedance of MOSFET is very high (of the order of 10^{10} to 10^{15} ohms).

2.5 Basic Operation and Characteristics of MOSFET

The Enhancement mode MOSFET is commonly used type of transistor. This type of MOSFET is equivalent to normally-open switch because it does not conduct when the gate (G) voltage is zero. The circuit diagram of an n-channel MOSFET (Enhancement mode, EMOSFET) with normal polarities is shown in the Figure (2-7). When negative voltage ($-V_{GS}$) is applied to the gate (G), electrons accumulate on it. These electrons repel or (prevent) the conduction band electrons in the n-channel. Therefore the number of conduction electrons available for current conduction through the channel will reduce. Thus, the greater the negative potential on the gate, the lesser is the current conduction from source to drain. In contrast, if the positive voltage ($+V_{GS}$) is applied to the n-channel gate terminal, then the channel conducts and the drain current flows through the channel.

In this case if the gate is given positive voltage, more electrons are made available in the n-channel. Consequently, the current from source to drain is increased.

If this bias voltage increases to more positive voltage then channel width and drain current (I_D) through the channel increased to some more. But if the bias voltage is zero or negative ($-V_{GS}$) then the transistor may switch OFF and the channel is in non-conductive state. So now we can say that the gate voltage of enhancement mode MOSFET enhances the conduction channel.

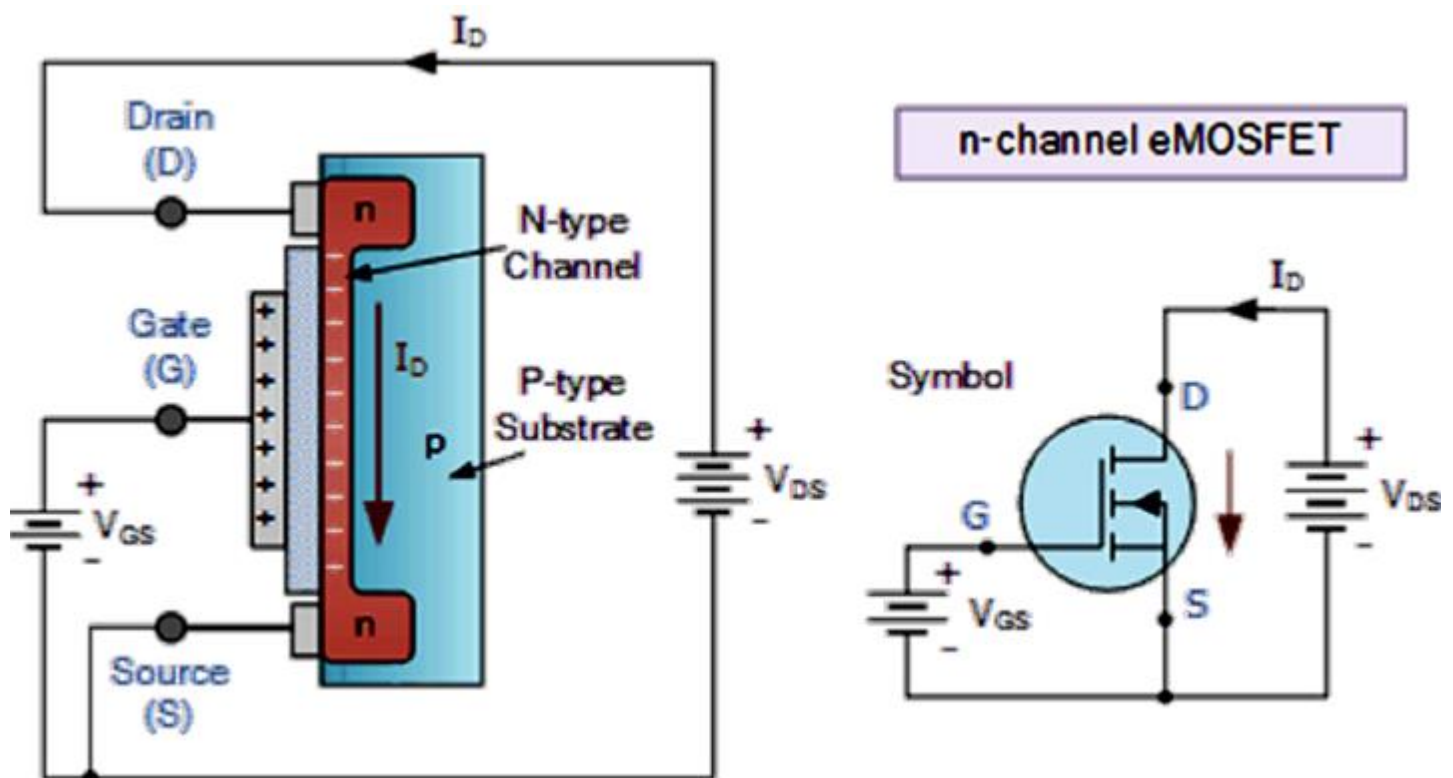
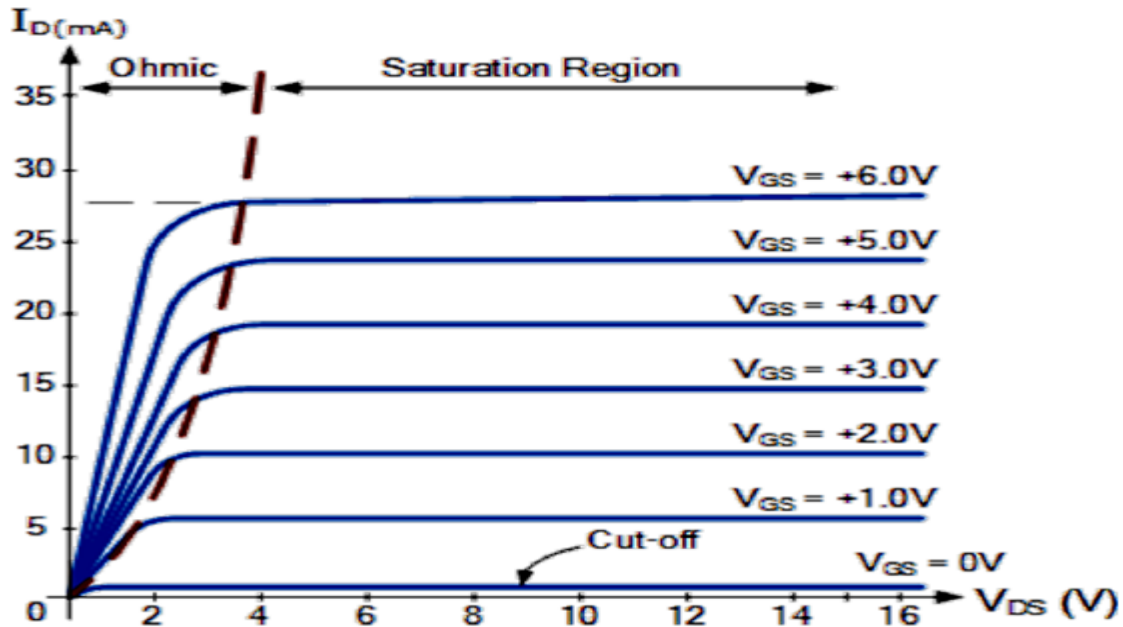


Figure (2-7): Scheme of Basic Operation of n-channel MOSFET (enhancement mode)

The V-I characteristics of enhancement mode MOSFET are shown below which gives the relationship between the drain current (I_D) and the drain-source voltage (V_{DS}). From the below Figure (2-8) we observed the behavior of an enhancement MOSFET in different regions, such as ohmic, saturation and cut-off regions.



Comparison of MOSFET and JFET

1. In enhancement and depletion types of MOSFET, the transverse electric field induced across an insulating layer deposited on the semiconductor material controls the conductivity of the channel. In the JFET the transverse electric field across the reverse biased PN junction controls the conductivity of the channel.
2. The gate leakage current in a MOSFET is of the order of 10^{-12} A. Hence the input resistance of a MOSFET is very high in the order of 10^{10} to 10^{15} ohm. The gate leakage current of a JFET is of the order of 10^{-9} A and its input resistance is of the order of 10^8 ohm.
3. The output characteristics of the JFET are flatter than those of the MOSFET and hence, the drain resistance of a JFET (0.1 to 1 Mohm) is much higher than that of a MOSFET (1 to 50 K ohm).
4. JFETs are operated only in the depletion mode. The depletion type MOSFET may be operated in both depletion and enhancement mode.
5. Comparing to JFET, MOSFETs are easier to fabricate.
6. MOSFET is very susceptible to overload voltage and needs special handling during installation. It gets damaged easily if it is not properly handled.
7. MOSFET has zero offset voltage. As it is a symmetrical device, the source and drain can be interchanged. These two properties are very useful in analog signal switching.
8. Special digital CMOS circuits are available which involve near-zero power dissipation and very low voltage and current requirements. This makes them most suitable for portable systems.

Comparison of JFET And BJT

1. FET operations depend only on the flow of majority carrier-holes for P-channel FETs and electrons for N-channel FETs. Therefore, they are called Unipolar devices. Bipolar transistor (BJT) operation depends on both minority and majority current carrier.
2. As FET has no junctions and the conduction is through an N-type or P-type semiconductor material, FET is less noisy than BJT.
3. As the input circuit of FET is reverse biased, FET exhibits as much higher input impedance (in the order of 100MOHM) and lower output impedance and there will be a high degree of isolation between input and output. So, FET can act as excellent buffer amplifier but the BJT has low input impedance because its input circuit is forward biased.
4. FET is a voltage control device, i.e. voltage at the input terminal controls the output current, whereas BJT is a current control device, i.e. the input current controls the output current.
5. FETs are much easier to fabricate and are particularly suitable for ICs because they occupy less space than BJTs.
6. The performance of BJT is degraded by neutron radiations because of reduction in minority carrier life time, whereas FET can tolerate a much higher level of radiation since they do not rely on minority carrier for their operation.
7. The performance of FET is relatively unaffected by ambient temperature changes. As it has a negative temperature coefficient at high current levels, it prevents the FET from thermal break down. The BJT has a positive temperature coefficient at high current levels which leads to thermal break down.
8. Since FET does not suffer from minority carrier storage effects, it has a higher switching speeds and cut off frequencies. BJT suffers a minority carrier storage effects and therefore has lower switching speed and cut off frequencies.
9. FET amplifiers have low gain bandwidth product due to the junction capacitive effects and produce more signal distortion except for small signal operation.
10. BJT are cheaper to produce than FETs.