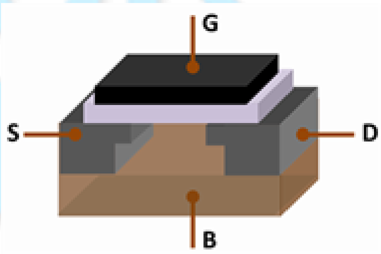
Important Questions on MOSFET

1) What is MOSFET?

Ans: MOSFET stands for Metal oxide semiconductor field effect transistor is a type of transistor that is controlled by voltage rather than current. The power MOS field effect transistor (MOSFET) evolved from the MOS integrated circuit technology. The new device promised extremely low input power levels and no inherent limitation to the switching speed. Thus, it opened up the possibility of increasing the operating frequency in power electronic systems resulting in reduction in size and weight. At high frequency of operation the required gate drive power becomes substantial. MOSFETs also have comparatively higher on state resistance per unit area of the device cross section which increases with the blocking voltage rating of the device.

MOSFET is a special type of field-effect transistor (FET) that works by electronically varying the width of a channel along which charge carriers flow. The wider the channel, the better the device conducts. The charge carriers enter the channel at the *source*, and exit via the *drain*. The width of the channel is controlled by the voltage on an electrode called the *gate*, which is located physically between the source and the drain and is insulated from the channel by an extremely thin layer of metal oxide.



2) Explain how MOSFET functions?

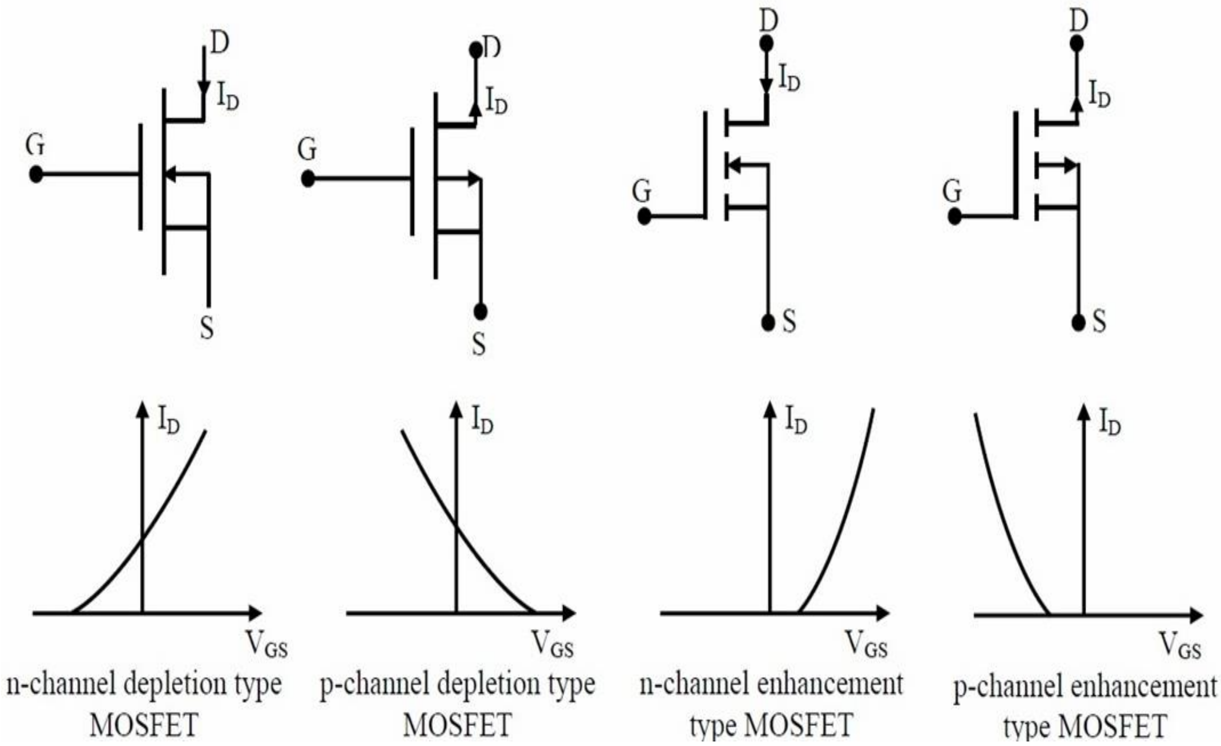
Ans: There are two ways in which a MOSFET can function.

- The first is known as *depletion mode*. When there is no voltage on the gate, the channel exhibits its maximum conductance. As the voltage on the gate increases (either positively or negatively, depending on whether the channel is made of P-type or N-type semiconductor material), the channel conductivity decreases.

- The second way in which a MOSFET can operate is called *enhancement mode*. When there is no voltage on the gate, there is in effect no channel, and the device does not conduct. A channel is produced by the application of a voltage to the gate. The greater the gate voltage, the better the device conducts.

3) Explain constructional features of a MOSFET.

Ans: Power MOSFET is a device that evolved from MOS integrated circuit technology. The first attempts to develop high voltage MOSFETs were by redesigning lateral MOSFET to increase their voltage blocking capacity. The resulting technology was called lateral double defused MOS (DMOS). However it was soon realized that much larger breakdown voltage and current ratings could be achieved by resorting to a vertically oriented structure. Since then, vertical DMOS (VDMOS) structure has been adapted by virtually all manufacturers of Power MOSFET. A power MOSFET using VDMOS technology has vertically oriented three layer structure of alternating p type and n type semiconductors. A large number of cells are connected in parallel to form a complete device.



The two n+ end layers labelled "Source" and "Drain" are heavily doped to approximately the same level. The p type middle layer is termed the body (or substrate) and has moderate doping level (2 to 3 orders of magnitude lower than n+ regions on both sides). The n- drain drift region has the lowest doping density. Thickness of this region determines the breakdown voltage of the device. The gate terminal is placed over the n- and p type regions of the cell structure and is insulated from the semiconductor body be a thin layer of silicon dioxide (also called the gate oxide). The source and the drain region of all cells on a wafer are connected to the same metallic contacts to form the Source and the Drain terminals of the complete device. Similarly all gate terminals are also connected together. The source is constructed of many (thousands) small polygon shaped areas that are surrounded by the gate regions. The geometric shape of the source regions, to same extent, influences the ON state resistance of the MOSFET.

One interesting feature of the MOSFET cell is that the alternating n+ n- p n+ structure embeds a parasitic BJT (with its base and emitter shorted by the source metallization) into each MOSFET cellThe nonzero resistance between the base and the emitter of the parasitic npn BJT arises due to the body spreading resistance of the p type substrate. In the design of the MOSFET cells special care is taken so that this resistance is minimized and switching operation of the parasitic BJT is suppressed. With an effective short circuit between the body and the source the BJT always remain in cut off and its collector-base junction is represented as an anti-parallel diode (called the body diode) in the circuit symbol of a Power MOSFET..

4) Explain the three regions of operation of a MOSFET.

Ans: Cut-off region: When $V_{GS} < V_t$, no channel is induced and the MOSFET will be in cut-off region. No current flows.
Triode region: When $V_{GS} \geq V_t$, a channel will be induced and current starts flowing if $V_{DS} > 0$. MOSFET will be in triode region as long as $V_{DS} < V_{GS} - V_t$.
Saturation region: When $V_{GS} \geq V_t$, and $V_{DS} \geq V_{GS} - V_t$, the channel will be in saturation mode, where the current value saturates. There will be little or no effect on MOSFET when V_{DS} is further increased.

5) What are the main constructional differences between a MOSFET and a BJT? What effect do they have on the current conduction mechanism of a MOSFET?

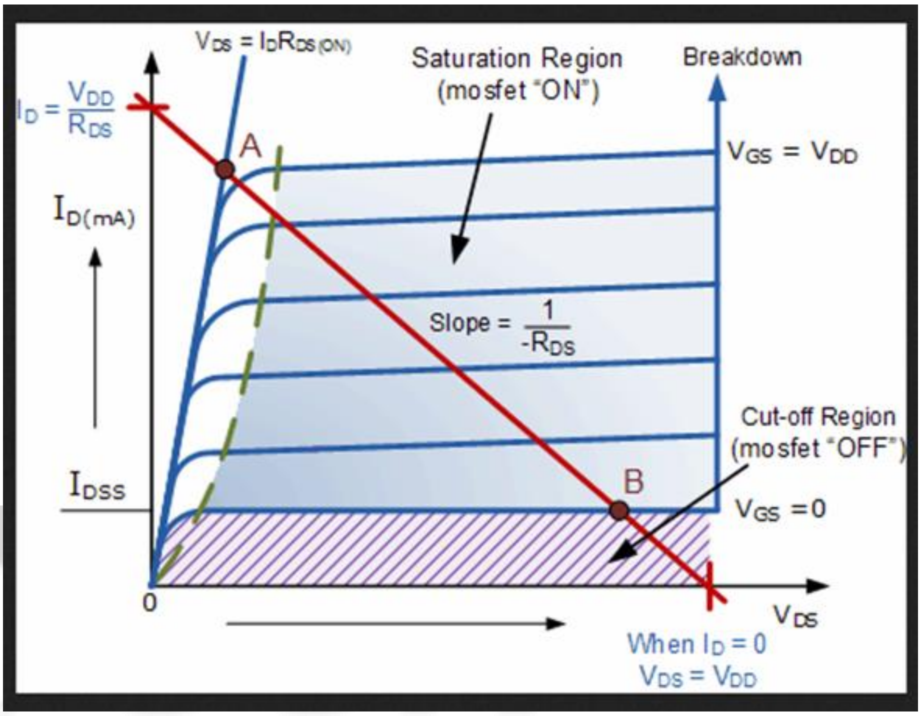
Ans: A MOSFET like a BJT has alternating layers of p and n type semiconductors. However, unlike BJT the p type body region of a MOSFET does not have an external electrical connection. The gate terminal is insulated for the semiconductor by a thin layer of SiO2. The body itself is shorted with n+ type source by the source metallization. Thus minority carrier injection across the source-body interface is prevented. Conduction in a MOSFET occurs due to formation of a high density n type channel in the p type body region due to the electric field produced by the gate-source voltage. This n type channel connects n+ type source and drain regions. Current conduction takes place between the drain and the source through this channel due to flow of electrons only (majority carriers) where as in a BJT, current conduction occurs due to minority carrier injection across the Base-Emitter junction. Thus a MOSFET is a voltage controlled majority carrier device while a BJT is a minority carrier bipolar device.

6) Write down advantages of MOSFET.

Ans: The MOSFET has certain advantages over the conventional junction FET, or JFET. Because the gate is insulated electrically from the channel, no current flows between the gate and the channel, no matter what the gate voltage (as long as it does not become so great that it causes physical breakdown of the metallic oxide layer). Thus, the MOSFET has practically infinite impedance. This makes MOSFETs useful for power amplifiers. The devices are also well suited to high-speed switching applications. Some integrated circuits (ICs) contain tiny MOSFETs and are used in computers. Because the oxide layer is so thin, the MOSFET is susceptible to permanent damage by electrostatic charges. Even a small electrostatic buildup can destroy a MOSFET permanently. In weak-signal radio-frequency (RF) work, MOSFET devices do not generally perform as well as other types of FET.

7) I-V characteristic of MOSFET.

Ans:



The MOSFET, like the BJT is a three terminal device where the voltage on the gate terminal controls the flow of current between the output terminals, Source and Drain. The source terminal is common between the input and the output of a MOSFET. The output characteristics of a MOSFET is then a plot of drain current (iD) as a function of the Drain – Source voltage (vDS) with gate source voltage (vGS) as a parameter.With gate-source voltage (VGS) below the threshold voltage (vGS (th)) the MOSFET operates in the cut-off mode. No drain current flows in this mode and the applied drain–source voltage (vDS) is supported by the body-collector p-n junction. Therefore, the maximum applied voltage should be below the avalanche break down voltage of this junction (VDSS) to avoid destruction of the device.
When VGS is increased beyond vGS(th) drain current starts flowing. For small values of vDS (vDS < (vGS – vGS(th)) iD is almost proportional to vDS. Consequently this mode of operation is called "ohmic mode" of operation. In power electronic applications a MOSFET is operated either in the cut off or in the ohmic mode. The slope of the vDS – iD characteristics in this mode is called the ON state resistance of the MOSFET .At still higher value of vDS (VDS > (VGS – vGS (th)) the iD – vDS characteristics deviates from the linear relationship of the ohmic region and for a given vGS, iD tends to saturate with increase in vDS. The exact mechanism behind this is rather complex. It will suffice to state that, at higher drain current the voltage drop across the channel resistance tends to decrease the channel width at the drain drift layer end. In addition, at large value of the electric field, produced by the large Drain – Source voltage, the drift velocity of free electrons in the channel tends to saturate. As a result the drain current becomes independent of VDS and determined solely by the gate – source voltage VGS. This is the active mode of operation of a MOSFET. Due to the presence of the anti-parallel "body diode", a MOSFET cannot block any reverse voltage. The body diode, however, can carry an RMS current equal to IDM. It

also has a substantial surge current carrying capacity. When reverse biased it can block a voltage equal to VDSS.
For safe operation of a MOSFET, the maximum limit on the gate source voltage (VGS (Max)) must be observed. Exceeding this voltage limit will cause dielectric break down of the thin gate oxide layer and permanent failure of the device. It should be noted that even static charge inadvertently put on the gate oxide by careless handling may destroy it. The device user should ground himself before handling any MOSFET to avoid any static charge related problem.

8) What is Forward Transconductance?

Ans: It is the **ratio** of iD and (vGS – vGS(th)). In a MOSFET switching circuit it determines the clamping voltage level of the gate – source voltage and thus influences dvDS/dt during turn on and turns off.

9) What does it mean "the channel is pinched off"?

Ans: For a MOSFET when V_{GS} is greater than V_t, a channel is induced. As we increase V_{DS} current starts flowing from Drain to Source (triode region). When we further increase V_{DS}, till the voltage between gate and channel at the drain end to become V_t, i.e. $V_{GS} - V_{DS} = V_t$, the channel depth at Drain end decreases almost to zero, and the channel is said to be pinched off. This is where a MOSFET enters saturation region.

10) What is body effect?

Ans: in an integrated circuit there will be several MOSFETs and in order to maintain cut-off condition for all MOSFETs the body substrate is connected to the most negative power supply (in case of PMOS most positive power supply). This causes a reverse bias voltage between source and body that effects the transistor operation, by widening the depletion region. The widened depletion region will result in the reduction of channel depth. To restore the channel depth to its normal depth the VGS has to be increased. This is effectively seen as change in the threshold voltage - V_t. This effect, which is caused by applying some voltage to body, is known as body effect.