Metal Oxide Semiconductor Field Effect Transistors (MOSFETs):

MOSFET is a type of Field Effect Transistor in which majority charge carriers flow in the channel. The width of the channel is controlled by an electrode called gate. Channel width determines how well the device conducts.

MOSFETS are useful in high-speed switching circuits and in Integrated Circuits.

There are two types of MOSFET's:

(i) Depletion type MOSFET
(ii) Enhancement type MOSFET

DEPLETION TYPE MOSFET:

Depletion-type MOSFETs are further classified as

(i) N-channel D-type MOSFET
(ii) P-Channel D-type MOSFET

N-CHANNEL DEPLETION TYPE MOSFET:

The basic construction of the n-channel depletion type MOSFET is as shown in fig (10). A slab of p-type material is formed from a Si base and is referred to as the substrate. The source and drain terminals are connected through metallic contacts to n-doped regions linked by a n-channel. The gate is also connected to a metal contact surface but remains insulated from the n-channel by a very thin SiO_2 layer. The presence of SiO_2 layer accounts for very high input impedance of the device. The input impedance of MOSFET is higher than JFET.

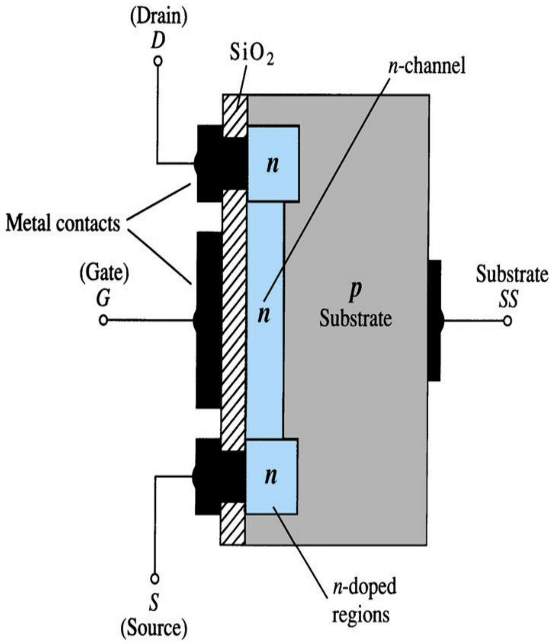

Fig 10: Construction n-Channel Depletion type MOSFET.

A small n layer is implanted in the region below SiO_2 to create n-channel. The insulating layer between gate and the channel has resulted in another name for the device : Insulated-gate FET or IGFET.

OPERATION OF N-CHANNEL DEPLETION MODE MOSFET:

Case i: V_{GS} = 0 and V_{DS} = +ve voltage

Since drain is positive with respect to source, the free electrons are attracted from source to drain to constitute drain current I_D. The drain characteristics and transfer characteristics of depletion mode MOSFET is as shown in fig 11.

Case ii: V_{GS} = -ve Voltage and V_{DS} = +ve small voltage

The negative potential at the gate will cause the electrons to move towards p-type substrate as charges repel while holes from p-type substrate are attracted toward gate. Depending on the magnitude of negative bias established by V_{GS}, a level of recombination between electrons and holes will occur that will reduce the number of free electrons in the n-channel available for conduction. The more negative the bias, higher is the rate of recombination. The resulting level of I_D is reduced with the increasing levels og negative bias for VGS as in fig11.

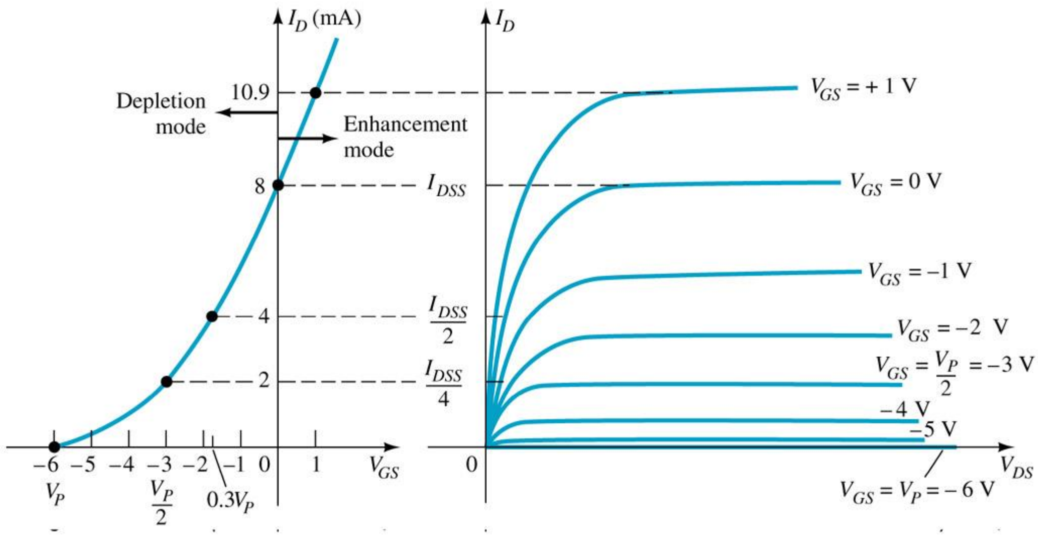

Fig11(a) Transfer Characteristics Fig 11(b) Drain Characteristics.

Case iii: V_{GS} = +ve Voltage and V_{DS} = +ve small voltage

For positive values of V_{GS}, the +ve gate will draw additional electrons from p-type substrate as minority charge carriers are attracted towards gate. New carriers are generated due to collisions and I_D will increase at a rapid rate. Thus, application of $+V_{GS}$ has enhanced the level of free carriers in the channel compared to V_{GS} = 0V. The region of +ve gate voltage on the drain or transfer characteristics is referred as enhancement region. The region between the cut-off and the saturation level of I_{DSS} is refereed as the depletion region.

Transfer characteristics are a plot of I_D as a function of V_{GS} with V_{DS} as constant. Shockley Equation as in equation 2 is used to plot transfer characteristics.

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

Also, Short hand method can be used to plot transfer characteristics curve.

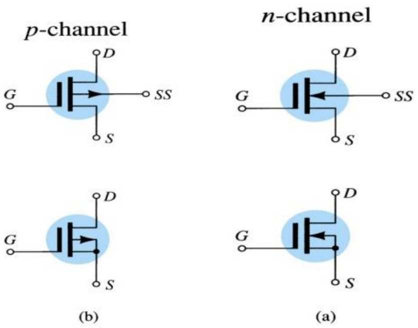

Fig 13 (a) n-channel depletion type MOSFET   (b) p-channel depletion type MOSFET

N-CHANNEL ENHANCEMENT-MODE MOSFET (E-MOSFET):
The construction of n-channel enhancement mode MOSFET is as shown in fig 14. The starting material is a p-type substrate into which highly doped n-regions are diffused to form source and drain regions. A layer of SiO_2 is grown allover the p-type substrate and is etched to create window for n-diffusion. The source and drain terminals are taken out through metallic contacts to n-doped regions as shown in fig 14. Metal is deposited on SiO2 to create Gate. The presence of SiO2 between gate and p-substrate provides electrical isolation between the two regions. No channel exists between source and drain in E-MOSFET.

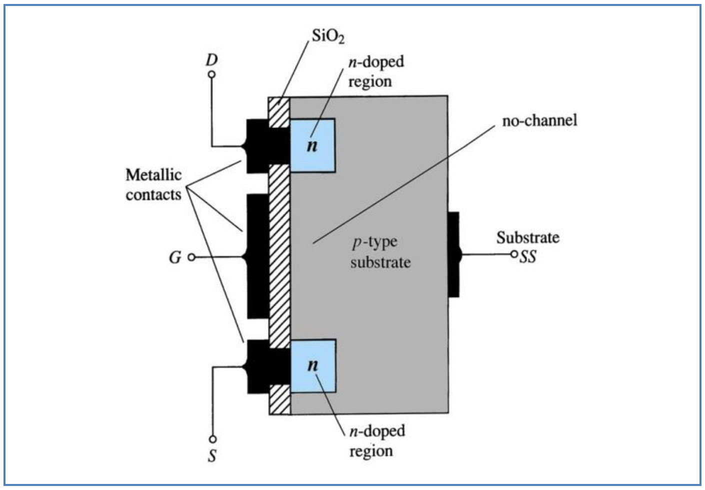

Fig 14: Construction of n-channel E-MOSFET

OPERATION OF N-CHANNEL E-MOSFET:

Case i: V_{GS} = 0 and V_{DS} = +ve voltage

The application of drain to source voltage while gate and source are shorted will cause no ID to flow as no channel exists for this condition.

Case ii: V_{GS} = +ve Voltage and V_{DS} = +ve small voltage

When gate is made positive with respect to source, electrons are attracted towards the gate but holes are repelled back into p-type substrate. Since the region under the gate is p-type substrate, the positive voltage on gate causes holes which are majority charge carriers in p-type substrate to repel and move towards substrate. A positive V_{GS} and positive V_{DS} causes the two pn junctions to be reverse biased and depletion region is formed. Now the device is said to be in depletion mode. The positive V_{GS} also causes electrons to be attracted towards the gate. Now, device is said to be in accumulation mode. Since the region below the gate was p-substrate and accumulation of electrons has caused the type to change to n-type. Thus the device is said to be in inversion mode as shown in fig 15. A positive V_{GS} has caused a thin layer of negative chargesto be formed in the substrate under the gate. Thus, channel is said to be created. The value of V_{GS} which causes channel to be formed under the gate is called threshold voltage(V_T). A small I_D flows. When V_{GS} is increased above V_T, conductivity of the channel is enhanced and thus pulling more electrons into the channel. When $V_{GS}<V_T$, there is no channel. Since channel is formed by the application of $+V_{GS}$, the type of MOSFET is Enhancement type. As V_{GS} is increased further, higher level of I_D flows as shown in fig 16. A positive V_{GS} cause potential drop across the channel. For large V_{DS} this voltage may not be sufficient to invert the channel near the drain end there by causing drain current to saturate. The channel is said to be pinched off. I_D flows due to diffusion.

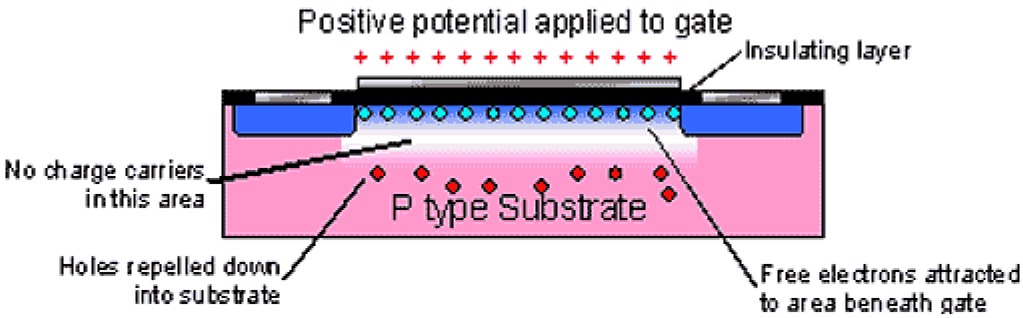

Fig 15: Formation of Inversion layer

TRANSFER CHARACTERISTICS OF N-CHANNELE-MOSFET:

The transfer characteristics of n-channel E-MOSFET is as shown in fig 16. For VGS >VT, the relationship between drain current and VGS is nonlinear and is given by eqn 4.

$$ID = K(VGS - VT)^2 \qquad \text{----------Eq 4}$$

Where K is a constant and is a function of the construction of the device as given by Eqn 5.

$$K = \frac{ID(ON)}{(VGS(ON) - VT)^2} \qquad \text{-----------Eq 5}$$

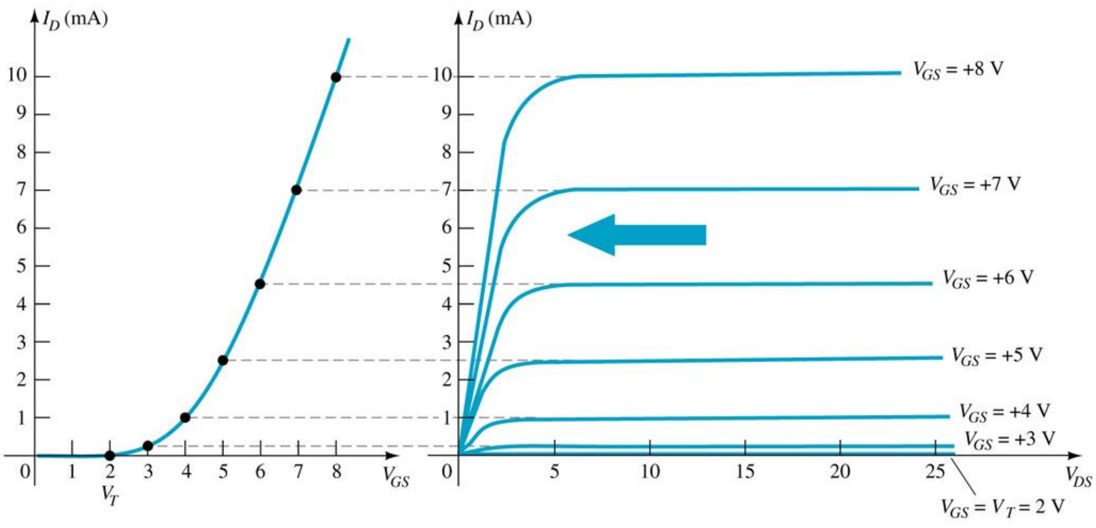

Fig16: Transfer Characteristics Drain Characteristics