1.6 Study of MOSFET

- MOSFET is metal oxide semiconductor field effect transistor.
- MOSFET is a three terminal device. The three terminals are gate (G), drain (D) andsource (S)
- MOSFET is a unipolar device as its operation depends on flow of majority charge carriersonly.
- It is a voltage controlled device requiring a small input gate voltage.
- It has high input impedance.
- MOSFET is operated in two states viz., ON STATE and OFF STATE.

A power MOSFET is a special type of metal oxide semiconductor field effect transistor. Itis specially designed to handle high-level powers. The power MOSFET's are constructed ina V configuration. Therefore, it is also called as V-MOSFET, VFET

Power MOSFETs are of two types

1. n- channel Enhancement MOSFETs
2. p- channel Enhancement MOSFETs

n-channel enhancement MOSFET is commonly used due to the higher mobility of electrons.

MOSFET CONSTRUCTION

Power MOSFETs are based on vertical structure, the doping and the thickness of the epitaxial layer decide the voltage rating while the channel width decides its current rating.This is the reason because of which they can sustain high blocking voltage and high current, making them suitable for low power switching applications.

The figure shows the planar diffused MOSFET structure for n-channel.

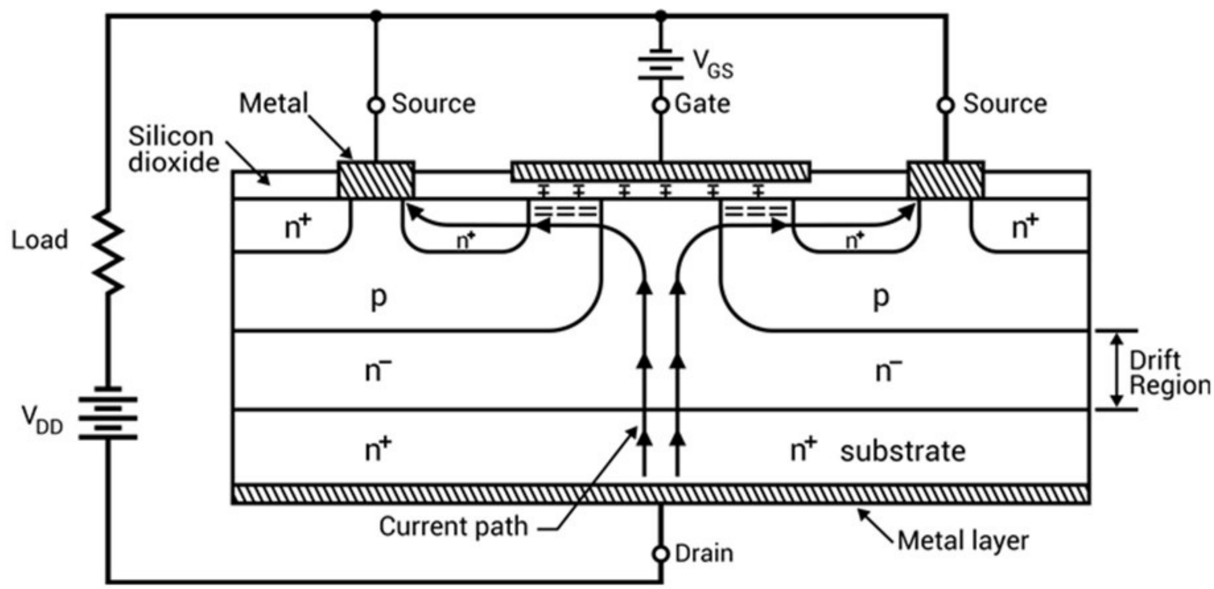

Fig 1.6.1 Structure of MOSFET

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers Page: 21]

On n+ substrate, high resistivity n- layer is epitaxial grown. The thickness of n- layer decides the voltage blocking capability of the power Mosfets. The lightly doped n-type semiconductor forms the main body of the device. Two heavily doped p-type regions are there in the body separated by a certain distance L. Now there is a thin layer of silicon dioxide (SiO2) on the top of the substrate which behaves as a dielectric. There is an aluminum plate fitted on the top of this SiO2 dielectric layer.

Most importantly, here, the Source (S) terminal is placed over the Drain (D) terminal forming a vertical structure. As a result, in VDMOS the current flows beneath the gate area vertically between the source and the drain terminals through numerous n+ sources conducting in-parallel. As a result, the resistance offered by the device during its ON state RDS(ON) is much lower than that in the case of normal MOSFETs which enablethem to handle high currents.

OPERATION OF MOSFET

When gate circuit voltage is zero, and VDD is present, n- -p- junction is reverse biased and no current flows from drain to source. When gate terminal is made positive with respect to source, an electric field is established and electrons form an n channel. With gate voltage increased, drain current also increases.The length of n channel can be controlled.

If we apply a positive voltage at gate (G). This will create positive static potential at the aluminum plate of the capacitor. Due to capacitive action, electrons gets accumulated just below the dielectric layer Now if we further increase the positive voltage at thegate terminal, after a certain voltage called threshold voltage, due to the electrostatic force, covalent bonds of the crystal just below the SiO2 layer start breaking. Consequently, electron-hole pairs get generated there. By applying the positive voltage at gate, we can control the drain current.

VI CHARACTERISTICS OF MOSFET

MOSFET can be in any of the in three operating regions viz.,

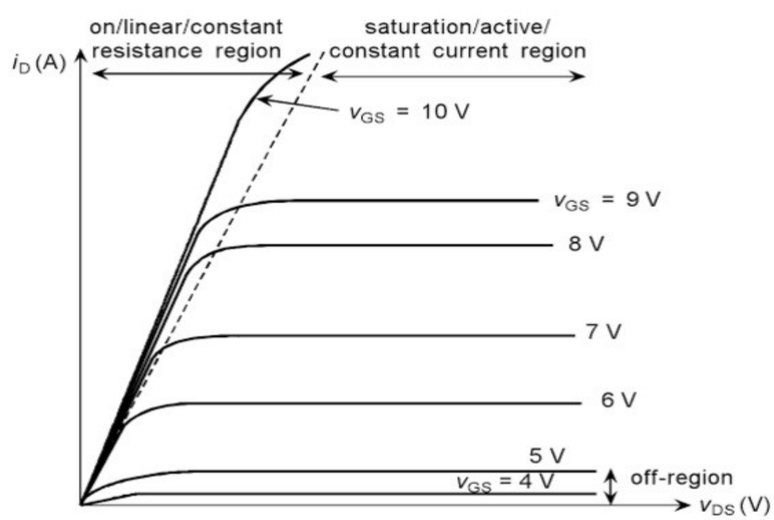

Fig 1.6.2 Characteristics of MOSFET

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers Page: 23]

Cut-Off Region

Cut-off region is a region in which the MOSFET will be OFF as there will be no current flow through it. In this region, MOSFET behaves like an open switch and is thus used when they are required to function as electronic switches.

Ohmic or Linear Region

Ohmic or linear region is a region where in the current IDS increases with an increase in the value of VDS. When MOSFETs are made to operate in this region, theycan be used as amplifiers.

Saturation Region

In saturation region, the MOSFETs have their IDS constant inspite of an increase in VDS and occurs once VDS exceeds the value of pinch-off voltage VP. Under this condition, the device will act like a closed switch through which a saturated value of IDS flows. As a result, this operating region is chosen whenever MOSFETs are required to perform switching operations.

From the transfer characteristics (drain-to-source current IDS versus gate-to-source voltage VGS), itis evident that the current through the device will be zero until the VGS exceeds the value of threshold voltage VT. This is because under this state, the device will be void of channel which will be connecting the drain and the source terminals. Under this condition, even an increase in VDS will result in no current flow as indicated by the corresponding output characteristics (IDS versus VDS). As a result this state represents nothing but the cut-off region of MOSFET's operation.

Next, once VGS crosses VT, the current through the device increases with an increase in IDS initially (Ohmic region) and then saturates to a value as determined by the VGS (saturation region of operation) i.e. as VGS increases, even the saturation current flowing through the device also increases. This is evident by Figure 1b where IDSS2 is greater than IDSS1 as VGS2> VGS1, IDSS3 is greater than IDSS2 as VGS3 >VGS2, so on and so forth. Further, Figure 1b also shows the locus of pinch-off voltage (black discontinuous curve), from which VP is seen to increase with an increase in VGS.

SWITCHING CHARACTERISTICS OF POWER MOSFET

The switching characteristics or the turn-on & turn-off times of the MOSFET are decidedby its internal capacitance and the internal impedance of the gate drive circuit. Turn on time is defined as the sum of turn on delay time and rise time of the device. Turn off time is the sum of turn off delay time and fall time

Turn ON Process:

A positive voltage is applied to the gate of MOSFET to turn e it on. When the gate voltage is applied, the gate to source capacitance CGS starts charging. When the voltage across CGS reached certain voltage level called Threshold voltage(VGST), the drain current ID starts rising.The time required to charge CGS to the threshold voltage level is known as turn ondelay time (td).The time required for charging CGS from threshold voltage to full gate voltage (VGSP). is called rise time (tr).During this period, the drain current rises to its full value, ie ID.Thus the MOSFET is fully turned ON.

The total turn-on time of MOSFET is

TON = tdon+ tr

The turn-on time can be reduced by using low-impedance gate drive source.

Turn OFF Process:

- To turn off the MOSFET, the gate voltage is made negative or zero.
- Due to this, the gate to source voltage then reduces from VI to VGSP.
- As MOSFET is a majority carrier device, turn-off process is initiated soon after removal of gate voltage at time t1.
- That is, CGS discharges from gate voltage V1 to VGSP. The time required for thisdischarge is called turn-off delay time (td(off))
- During this period, the drain current also starts reducing.
- The CGS keeps on discharging and its voltage becomes equal to threshold voltage(VGST).

- The time required to discharge CGS from VGSP to VGST is called fall time (tf). The drain current becomes zero when VGS < VGST. The MOSFET is then said to be have turned-off.
- Thus the total turn-off time of MOSFET is $T_{OFF} = t_{(d(off))} + t_f$
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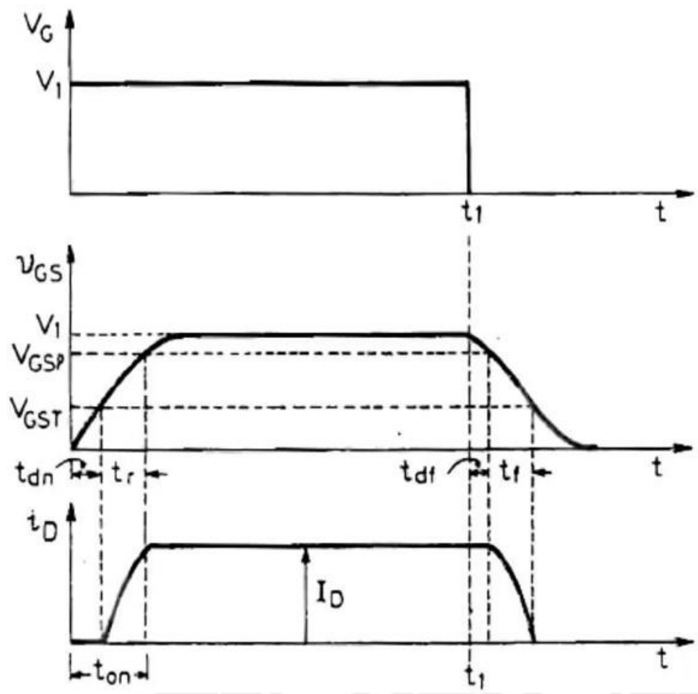

Fig.1.6.3 turn on and off characteristics of MOSFET

[Source: "Power Electronics" by P.S.Bimbra, Khanna Publishers Page: 23]

Applications of POWER MOSFET

Power MOSEFET technology is applicable to many types of circuit.

1. Linear power supplies
2. Switching power supplies
3. DC-DC converters
4. Low voltage motor control