Shariatpur polytechnic Institute

INDUSTRIAL ELECTRONICS

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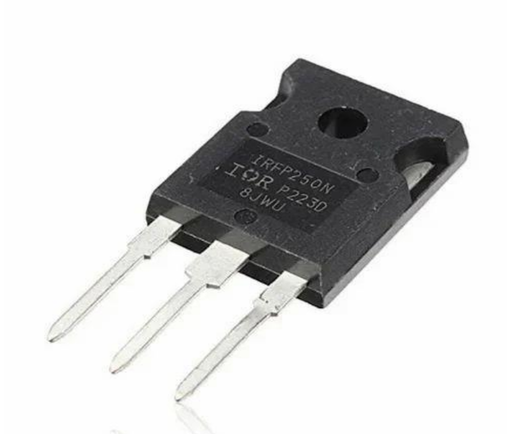
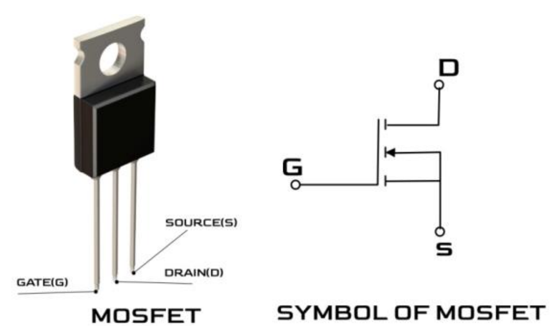
Chapter-02
MOSFET & IGBT

MOSFET:

MOSFET stands for Metal Oxide Field Effect Transistor, MOSFET was invented to overcome the disadvantages present in FETs like high drain resistance, moderate input impedance, and slower operation. So a MOSFET can be called the advanced form of FET. In some cases, MOSFETs are also be called IGFET (Insulated Gate Field Effect Transistor). Practically speaking, MOSFET is a voltage-controlled device, meaning by applying a rated voltage to the gate pin, the MOSFET will start conducting through the Drain and Source pin.





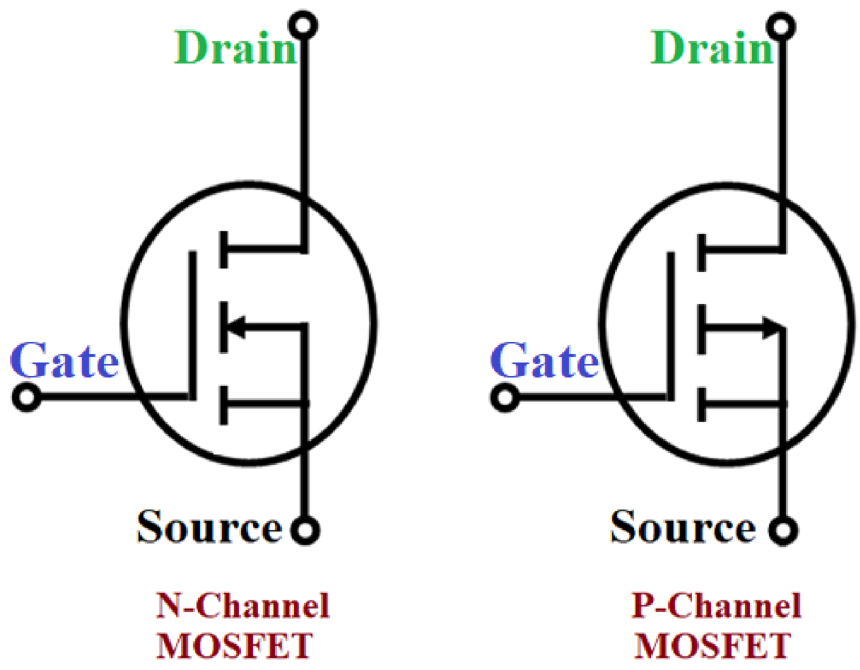
Classification of MOSFET

The MOSFET is Classified into two types based on the type of operations, namely Enhancement mode MOSFET (E-MOSFET) and Depletion mode MOSFET (D-MOSFET), these MOSFETs are further classified based on the material used for construction as n-channel and p-channel. So, in general, there are 4 different types of MOSFETs

- N-Channel Depletion mode MOSFET
- P-Channel Depletion mode MOSFET
- N-Channel Enhancement mode MOSFET
- P-Channel Enhancement mode MOSFET

Symbol Of MOSFET

In general, the MOSFET is a four-terminal device with a **Drain (D), Source (S), gate (G)** and a Body (B) / Substrate terminals. The body terminal will always be connected to the source terminal hence, the MOSFET will operate as a three-terminal device. In the below image, the **symbol of N-Channel MOSFET** is shown on the left and the **symbol of P-Channel MOSFET** is shown on the right.



Classification of a Power Transistor

Power transistors are classified into the following types:

- ✓ Bipolar Junction Transistors (BJTs)
- ✓ Metal Oxide Semiconductor Field-Effect Transistor (MOSFETs)
- ✓ Static Induction Transistor (SITs)
- ✓ Insulated Gate Bipolar Transistor (IGBTs)

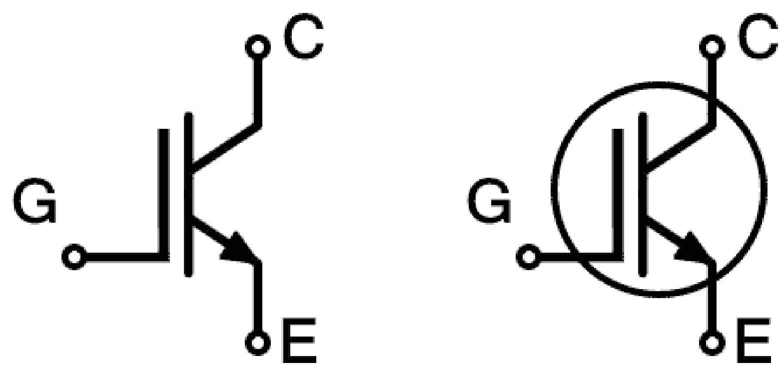
Applications of a Power Transistor

The applications of a power transistor are as follows:

- ✓ It is used in converters.
- ✓ It is also used in relays.
- ✓ It is used in an inverter.
- ✓ It is used for the amplification of the power as a power amplifier in electronic devices.
- ✓ It is also used in DC to AC converters.
- ✓ It is used in the supply of power.
- ✓ It is used in power control circuits too.
- ✓ It is also used in switch-mode power supplies which are also known as SMPS.
- ✓ It is also used in audio devices.

IGBT

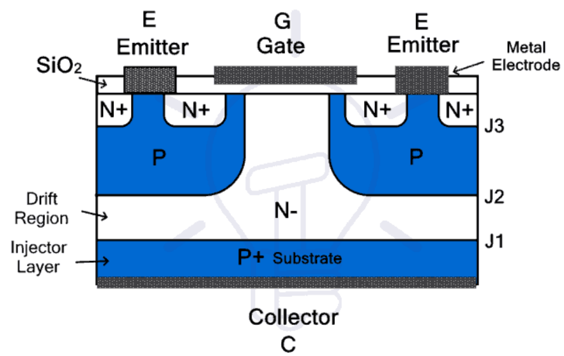
- The **IGBT or Insulated Gate Bipolar Transistor** is the combination of BJT AND MOSFET. Its name also implies the fusion between them. "Insulated Gate" refers to the input part of MOSFET having very high input impedance. It does not draw any input current rather it operates on the voltage at its gate terminal. "Bipolar" refers to the output part of the BJT having bipolar nature where the current flow is due to both types of charge carriers. It allows it to handle very large currents and voltages using small voltage signals. This hybrid combination makes the IGBT a voltage-controlled device.



IGBT - Insulated-Gate Bipolar Transistor Symbol

Construction of IGBT

IGBT is made of four layers of semiconductor to form a PNPN structure. The collector (C) electrode is attached to P layer while the emitter (E) is attached between the P and N layers. A P+ substrate is used for the construction of IGBT. An N- layer is placed on top of it to form PN junction J1. Two P regions are fabricated on top of N- layer to form PN junction J2. The P region is designed in such a way to leave a path in the middle for the gate (G) electrode. N+ regions are diffused over the P

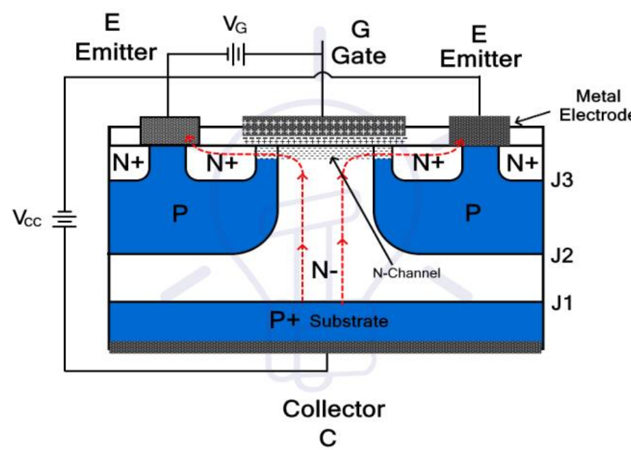


Structure of IGBT

The emitter and gate are metal electrodes. The emitter is directly attached to the N+ region while the gate is insulated using a silicon dioxide layer. The base P+ layer inject holes into N- layer that is why it is called injector layer. While the N- layer is called the drift region. Its thickness is proportional to voltage blocking capacity. The P layer above is known as the body of IGBT.
The N- layer is designed to have a path for current flow between the emitter and collector through the junction using the channel that is created under the influence of the voltage at the gate electrode.

Working of IGBT

- ❑ The two terminals of IGBT collector (C) and emitter (E) are used for the conduction of current while the gate (G) is used for controlling the IGBT. Its working is based on the biasing between Gate-Emitter terminals and Collector-Emitter terminals.
- ❑region as shown in the figure.



Working of IGBT

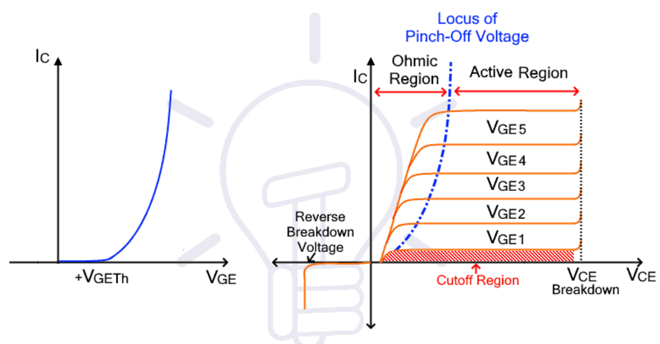
- ❑ The collector-emitter is connected to Vcc such that the collector is kept at a positive voltage than the emitter. The junction j1 becomes forward biased and j2 becomes reverse biased. At this point, there is no voltage at the gate. Due to reverse j2, the IGBT remains switched off and no current will flow between collector and emitter.

- Applying a gate voltage V_G positive than the emitter, negative charges will accumulate right beneath the SiO_2 layer due to capacitance. Increasing the V_G increases the number of charges which eventually form a layer when the V_G exceeds the threshold voltage, in the upper P-region. This layer form N-channel that shorts N- drift region and N+ region.

- The electrons from the emitter flow from N+ region into N- drift region. While the holes from the collector are injected from the P+ region into the N- drift region. Due to the excess of both electrons and holes in the drift region, its conductivity increase and starts the conduction of current. Hence the IGBT switches ON.

V-I Characteristics of IGBT

Unlike BJT, IGBT is a voltage-controlled device that requires only a small voltage at its gate to control the collector current. However, the gate-emitter voltage V_{GE} needs to be greater than the threshold voltage.
Transfer characteristics of the IGBT show the relation of input voltage V_{GE} to output collector current I_C. When the V_{GE} is 0v, there is no I_C and the device remains switched off. When the V_{GE} is slightly increased but remains below threshold voltage V_{GET}, the device remains switched off but there is a leakage current. When the V_{GE} exceeds the threshold limit, the I_C starts to increase and the device SWITCH ON. Since it is a unidirectional device, the current only flows in one direction.

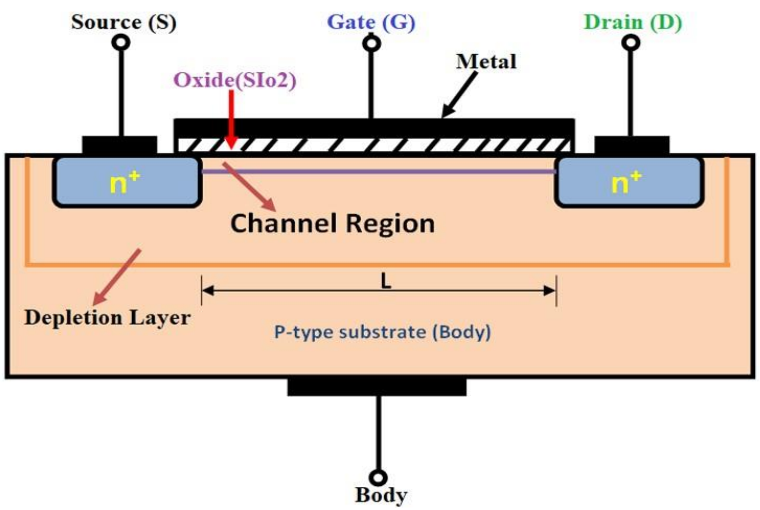


I-V Characteristics of IGBT

The given graph shows the relation between the collector current I_C and collector-emitter voltage V_{CE} at different levels of V_{GE}. At $V_{GE} < V_{GET}$ the IGBT is in **cutoff mode** and the $I_C = 0$ at any V_{CE}. At $V_{GE} > V_{GET}$, the IGBT goes into active mode, where the I_C increases with an increase in V_{CE}. Furthermore, for each V_{GE} where $V_{GE1} < V_{GE2} < V_{GE3}$, the I_C is different.
The reverse voltage should not exceed the reverse breakdown limit. So does the forward voltage. If they exceed their respective breakdown limit, uncontrolled current starts passing through it.

Construction Of MOSFET

The below image shows the typical internal structure of the MOSFET. Although the MOSFET is an advanced form of FET and operates with the same three terminals as a FET the internal structure of the MOSFET is really different from the general FET.



- *If you look at the structure, you could see that the gate terminal is fixed on the thin metal layer which is insulated by a layer of Silicon Dioxide (SiO2) from the semiconductor, and you will be able to see two N-type semiconductors fixed in the channel region where the drain and source terminals are placed.The channel between the drain and source of the MOSFET is an N-type, opposite to this, the substrate is implemented as P-type.This helps in biasing MOSFET in both the polarities, either positive or negative. If the gate terminal of the MOSFET isn't biased, it will stay in the non-conductive state, hence the MOSFET is mostly used in designing switches and logic gates.*

Working Principle of MOSFET

- In general, the MOSFET works as a switch, the MOSFET controls the voltage and current flow between the source and drain.The working of the MOSFET depends on the M O S capacitor, which is the semiconductor surface below the oxide layers between the source and drain terminal. It can be inverted from p-type to n-type, simply by applying positive or negative gate voltage respectively.The below image shows the block diagram of the MOSFET.

- When a drain-source voltage (V_{DS}) is connected between the drain and source, a positive voltage is applied to the Drain, and the negative voltage is applied to the Source. Here the PN junction at the drain is reverse biased and the PN junction at the Source is forward biased. At this stage, there will not be any current flow between the drain and the source.

- If we apply a positive voltage (V_{GG}) to the gate terminal, due to electrostatic attraction the minority charge carriers (electrons) in the P substrate will start to accumulate on the gate contact which forms a conductive bridge between the two n+ regions.The number of free electrons accumulated at the gate contact depends on the strength of positive voltage applied.The higher the applied voltage greater the width of the n-channel formed due to electron accumulation, this eventually increases the conductivity and the **drain current (I_D)** will start to flow between the Source and Drain.

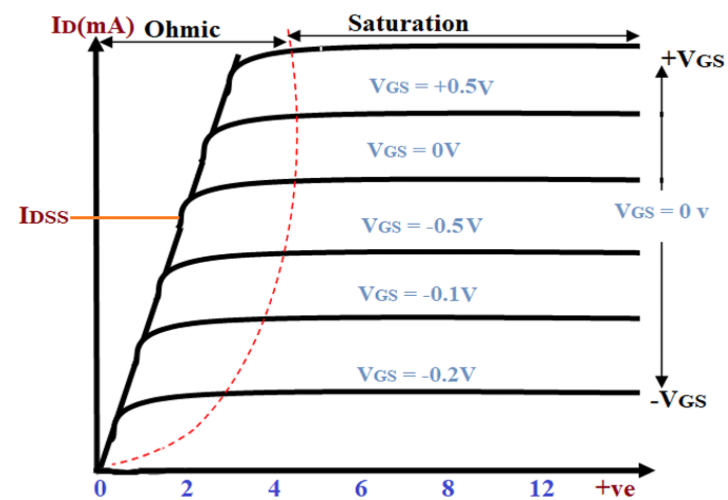
- *When there is no voltage applied to the gate terminal, there will not be any current flow apart from a small amount of current due to minority charge carriers.The minimum voltage at which the MOSFET starts conducting is called the* ***threshold voltage****.*

Operation of MOSFET in Depletion Mode:

The depletion-mode MOSFETs are usually called the "Switched ON" devices as they are generally in the closed state when there is no bias voltage at the gate terminal. When we increase the applied voltage to the gate in positive the channel width will be increased in depletion mode. This will increase the drain current I_D through the channel. If the applied gate voltage is highly negative, then the channel width will be less and the MOSFET might enter into the cutoff region.

V-I characteristics:

The V-I characteristics of the depletionmode MOSFET transistor are drawn between the drain-source voltage (V_{DS}) and Drain current (I_D). The small amount of voltage at the gate terminal will control the current flow through the channel. The channel formed between the drain and the source will act as a good conductor with zero bias



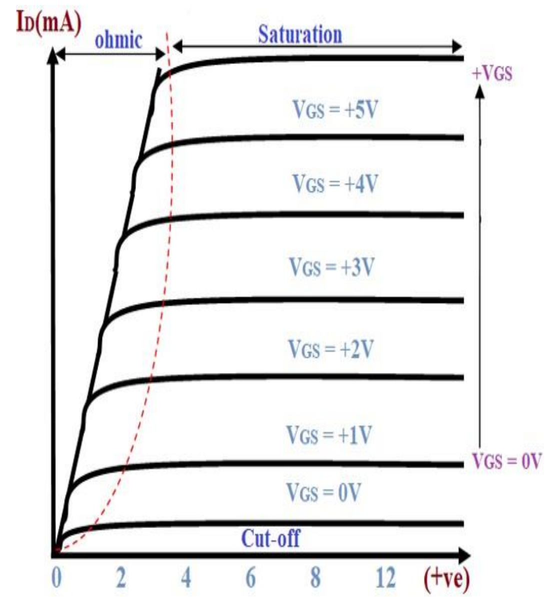
voltage at the gate terminal. The channel width and drain current will increase if the positive voltage is applied to the gate whereas they will get decreased when we apply a negative voltage to the gate.

Operation of MOSFET in Enhancement Mode:

The operation of MOSFET in Enhancement mode is similar to the operation of theopen switch, it will start to conduct only if the positive voltage(+V_{GS}) is applied to the gate terminal and the drain current starts to flow through the device.The channel width and drain current will increase when the bias voltage increases. But if the applied bias voltage is zero or negative the transistor will remain in the OFF state itself.

V-I Characteristics:

VI characteristics of the enhancement-mode MOSFET are drawn between the drain current (I_D) and the drain-source voltage (V_{DS}). The VI characteristics are partitioned into three different regions, namely ohmic, saturation, and cut-off regions. The cutoff region is the region



where the MOSFET will be in the OFF state where the applied bias voltage is zero. When the bias voltage is applied, the MOSFET slowly moves towards conduction mode, and the slow increase in conductivity takes place in the ohmic region. Finally, the saturation region is where the positive voltage is applied constantly and the MOSFET will be staying in the conduction state.

Difference between IGBT and MOSFET

The important differences between IGBT and MOSFET are listed in the following table:

Basis of Comparison	MOSFET	IGBT
Full form	MOSFET stands for Metal Oxide Semiconductor Field Effect Transistor.	IGBT stands for Insulated Gate Bipolar Transistor.
Type of conduction	MOSFET is a unipolar conduction device.	IGBT is a bipolar conduction device.
Types	Types of MOSFETs are Depletion-Mode MOSFET and Enhancement-Mode MOSFET.	Types of IGBT are Punch Through IGBT and Non-Punch Through IGBT.
Terminals	MOSFET has three terminals namely, Source (S), Gate (G), and Drain (D).	IGBT has three terminals namely, Emitter (E), Gate (G), and Collector (C).
Voltage rating	MOSFET has a lower voltage rating than IGBT.	IGBT has a higher voltage rating.
Switching speed	The switching speed of MOSFET is faster.	IGBT has a lower switching speed.
On-state voltage drop	The on-state voltage drop in a MOSFET is high.	The on-state voltage drop in an IGBT is low.
Energy efficiency	MOSFET is comparatively less energy efficient.	IGBT is more energy efficient.
Noise immunity	MOSFET is more immune to noise.	IGBT is comparatively less immune to noise.
Cost	MOSFET is less costly.	IGBT is costlier than MOSFET.


Any Questions


THANK YOU
FOR YOUR
ATTENTION