Power Electronics

Dr. Satish Chandra

Difference between transistor and power transistor

- A transistor is a three or four-terminal electronic device.
- On applying an input current to a pair of the terminals of the transistor, one can observe a change in current in another terminal of that transistor.
- An ordinary transistor acts like a **switch** or an **amplifier**.
- Whereas a power transistor acts like a **heat sink**, which protects the circuit from damage.
- It is larger in size than a normal transistor.

Types

- Power BJT
- Power MOSFET

Power BJT

- The power bipolar junction transistor (BJT)
  - blocks a high voltage in the off state and
  - high current carrying capacity in the on-state.
- The power handling capacity is very high.

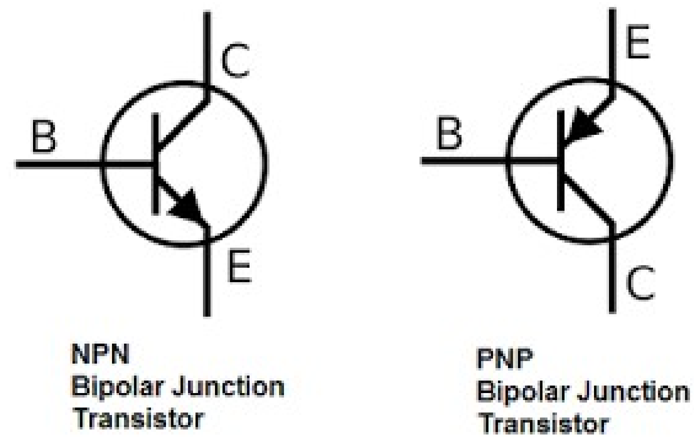
Power BJT

The following are the characteristics of a Power BJT, they are

- It has a **larger size**, so that maximum current can flow through it.
- The **breakdown voltage is high.**
- It has higher current carrying and **high-power handling capability.**
- It has a higher on-state voltage drop.
- High power application.

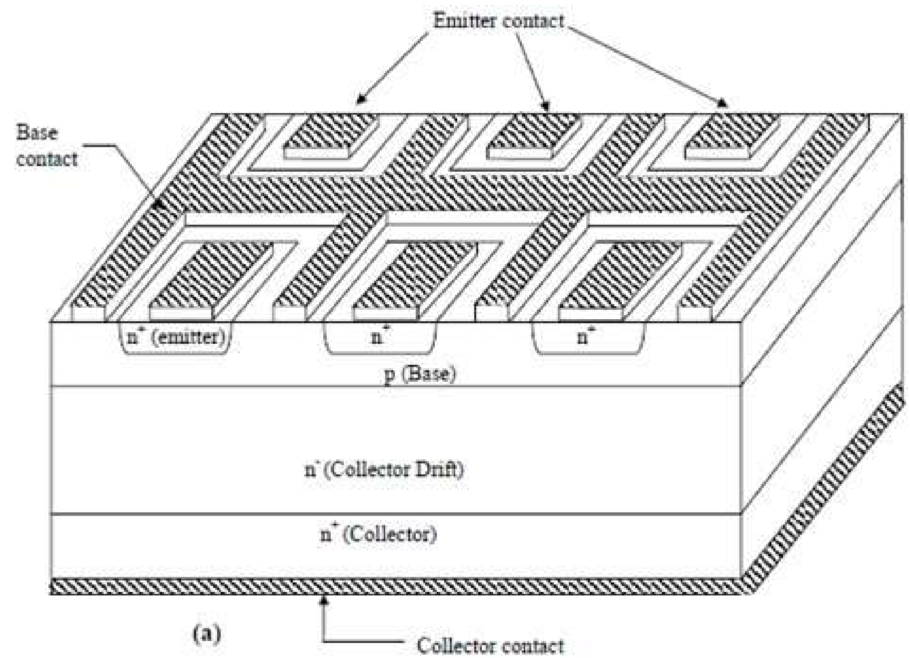
Construction of Power BJT

- There are two types of BJT;
  - n-p-n transistor and
  - p-n-p transistor.
- Out of these two types, the n-p-n transistors widely use compare to the p-n-p transistor.



Construction of Power BJT

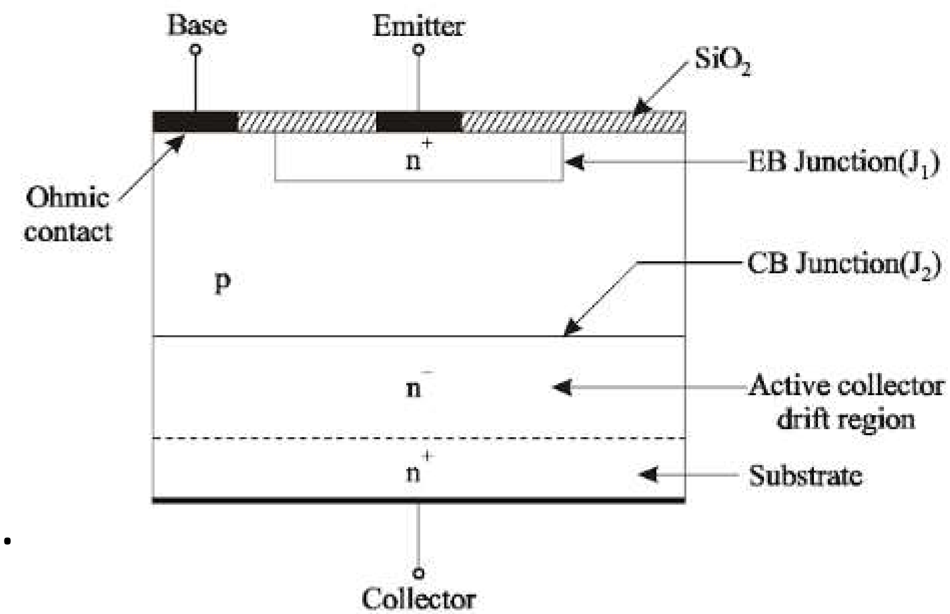
- The construction of the Power Transistor is different from the signal transistor as shown in the following figure.
- The n- layer is added in the power BJT which is known as **drift region**.



(a)

Construction of Power BJT

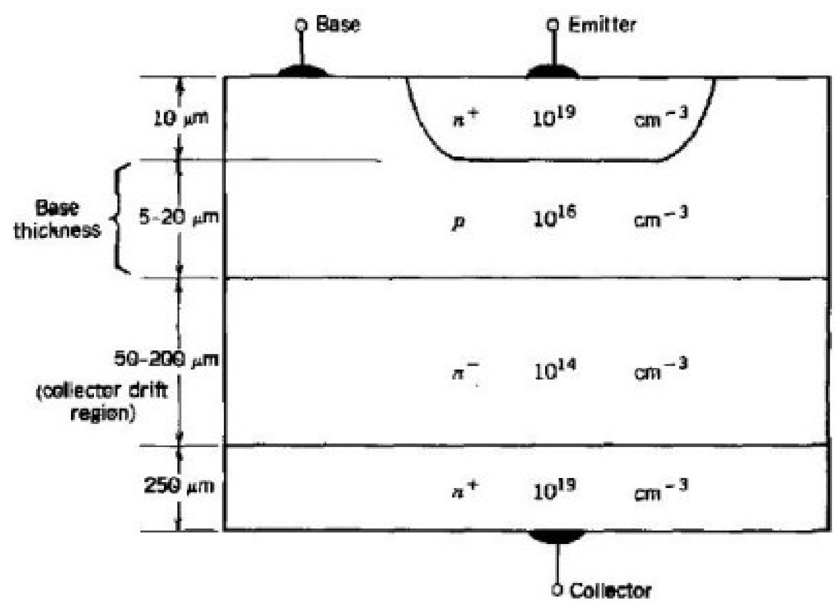
- The power BJT has three terminals Collector (C), Emitter (E) and Base (B).
- It has a vertically oriented **four-layers** structure.
- The vertical structure uses to increase the cross-sectional area.



Construction of Power BJT

It has four layers.

- The first layer is a **heavily** doped emitter layer (n+).
- The second layer is **moderately** doped the base layer (p).
- The third region is **lightly** doped collector drift region (n-).
- The last layer is a **highly** doped collector region (n+).



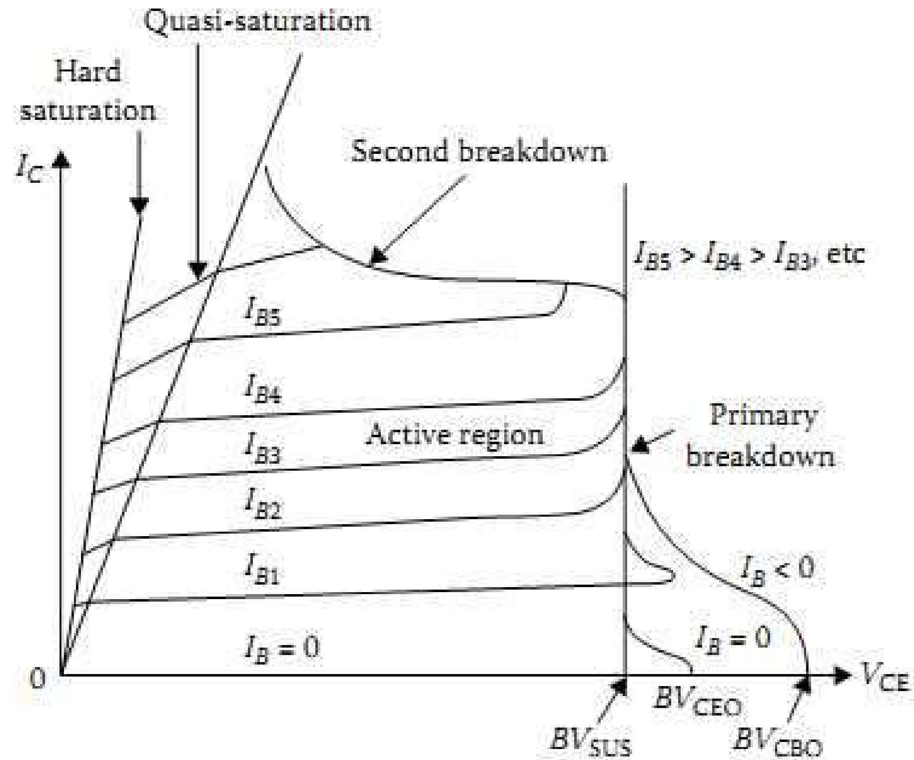
Construction of Power BJT

- The drift layer (n-) increase the **voltage blocking capacity** of the transistor due to the low doping level.
- The width of this layer decides the **breakdown voltage**.
- The disadvantage of this layer is that the increase on voltage drops and increase on device resistance, which **increases power loss**.
- The **power handling capacity** of the power transistor is very large. So, they have to dissipate power in the form of heat.
- Sometimes, **heatsink** uses to increase effective area and therefore increase power dissipation capacity. The heatsink made from metal.

I-V characteristic

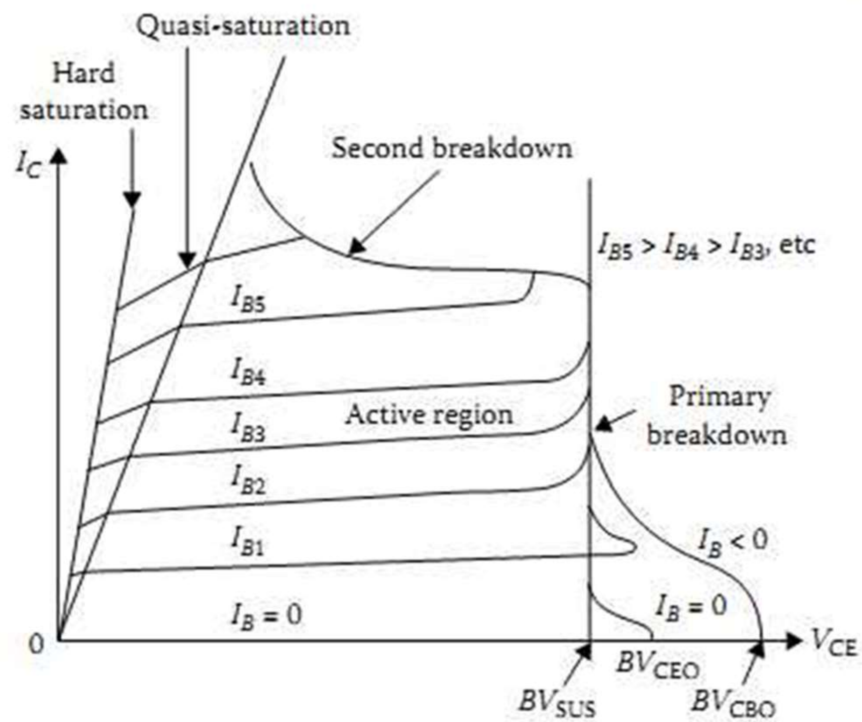
The I-V characteristic of Power BJT divides into four regions.

1. Cut-off region
2. Active region
3. Quasi-saturation region
4. Hard saturation region



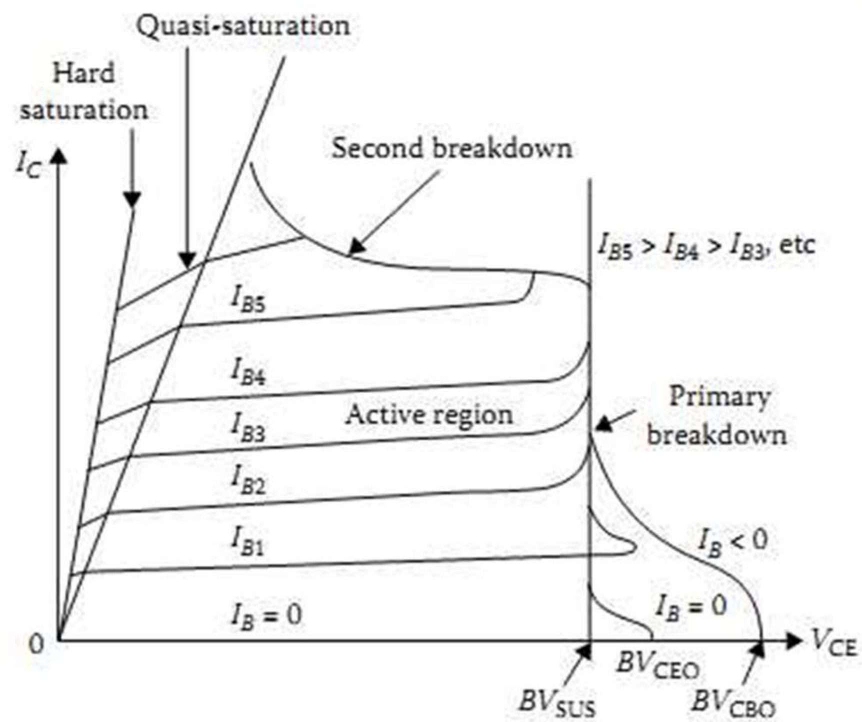
Cut-off region

- The BE and CB **both junctions** are **reverse bias**.
- The base current $I_B = 0$ and collector current I_C is equal to the **reverse leakage current** I_{CEO}.
- The region below the characteristic for $I_B = 0$ is cut-off region.
- In this region, BJT offers large resistance to the flow of current.
- Hence it is equivalent to an open circuit.



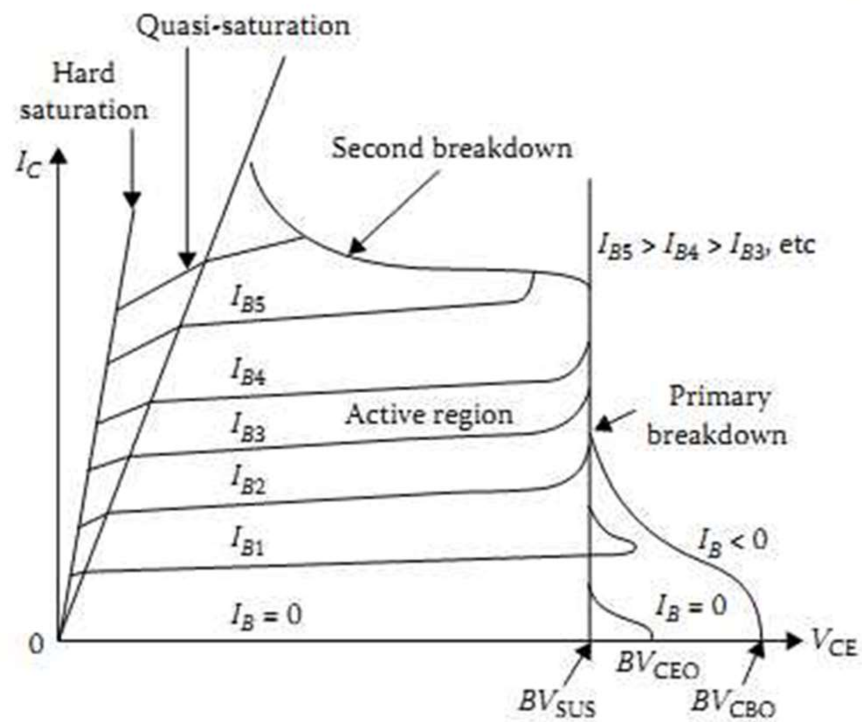
Active region

- The **BE junction is forward bias and CB junction is reverse bias**.
- The collector current I_C increase slightly with an increase in the voltage V_{CE} if I_B is increased.
- The relation of I_B and I_C is, $I_C = \beta_{dc} I_B$ is true in the active region.
- If BJT uses as an amplifier or as a series pass transistor in the voltage regulator, it operates in this region.
- The dynamic resistance in this region is large. The **power dissipation is maximum**.



Quasi-saturation region

- Quasi-saturation region is between the hard saturation and active region.
- This region exists **due to the lightly doped drift layer**.
- When the BJT operates at high frequency, it is operated in this region.
- **Both junctions are forward bias**.
- The device offers **low resistance** compared to the active region. So, power loss is less.
- In this region, the device does not go into deep saturation. So, it can **turn off quickly**. Therefore, we can use for **higher frequency** applications.



Hard-saturation region

- The Power BJT push into the hard-saturation region from the quasi-saturation region by increasing the base current.
- The **resistance** offers in this region is **minimum**. It is even less than the quasi-saturation region. So, when the BJT operates in this region, power **dissipation is minimum**.
- The device acts as a closed switch when it operates in this region. But it needs **more time to turn off**. So, this region is suitable only for **low-frequency** switching application.
- In this region, **both junctions are forward bias**.
- This region is also known as deep saturation region.

Application of Power BJT

- Switched Mode Power Supply (SMPS)
- Power Amplifier
- Relay and Drivers
- AC motor speed controller
- DC/AC inverter
- As series pass transistor in the regulated power supply
- The audio amplifier in the stereo system
- Power control circuit

Power BJT

Advantages

The advantages of power BJT are,

- Voltage gain is high.
- The density of the current is high.
- The forward voltage is low.
- The gain of bandwidth is large.

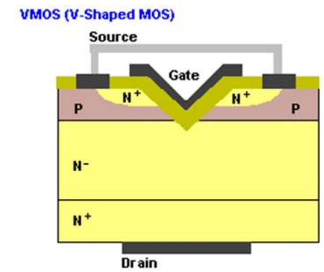
Disadvantages

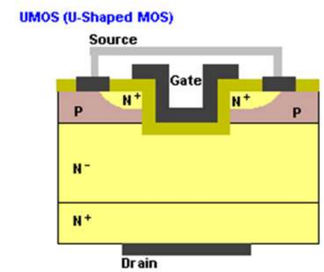
The disadvantages of power BJT are,

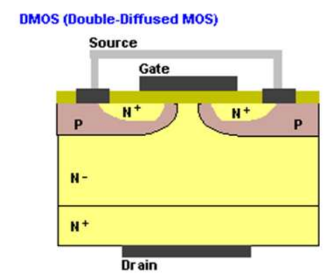
- Thermal stability is low.
- It is noisier.
- Controlling is a bit complex.

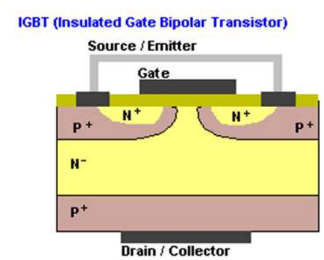
Power MOSFET

- A type of metal oxide semiconductor field effect transistor (MOSFET) used to switch large amounts of current.
- Power MOSFETs use a **vertical structure** with **source and drain terminals at opposite sides** of the chip.
- The vertical orientation eliminates crowding at the gate and offers **larger channel widths**.
- In addition, thousands of these transistor "cells" are combined into one in order to handle the high currents and voltage required of such devices.

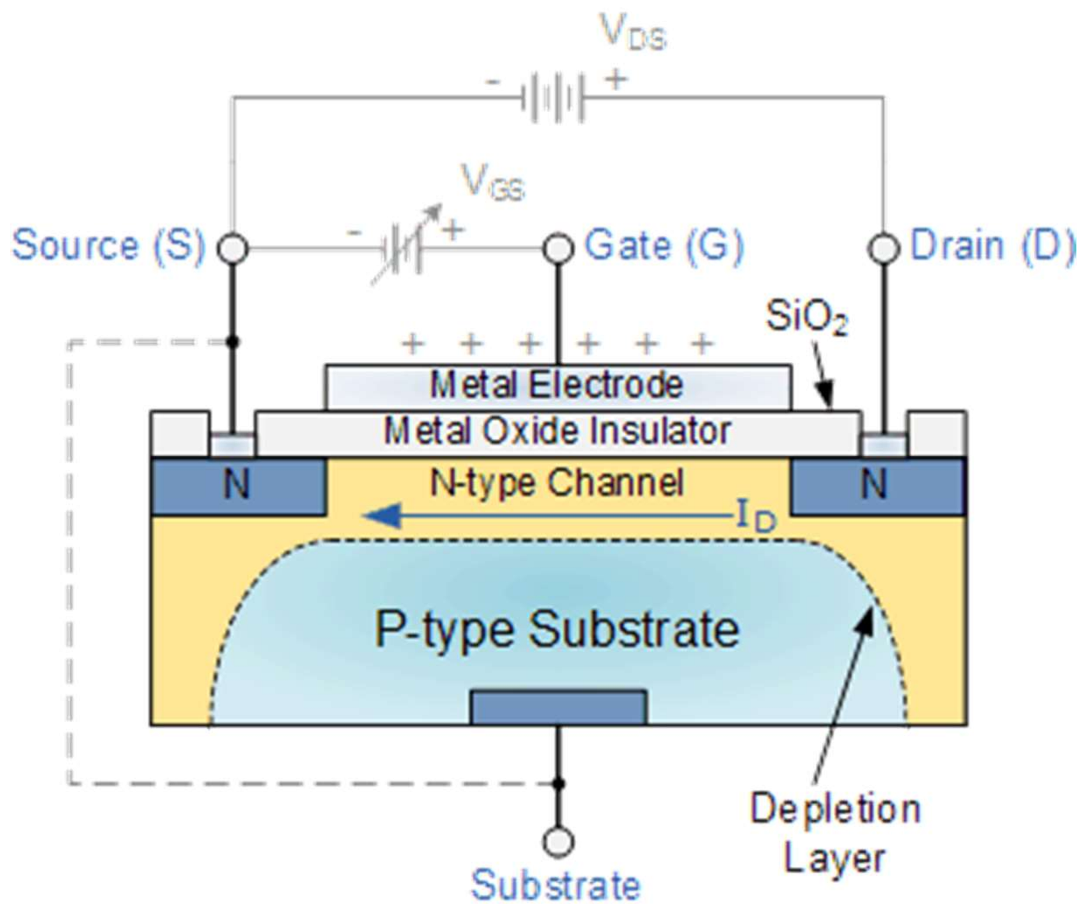








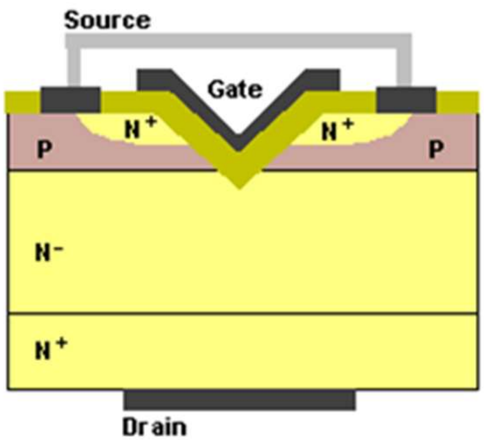
General MOSFET - Construction



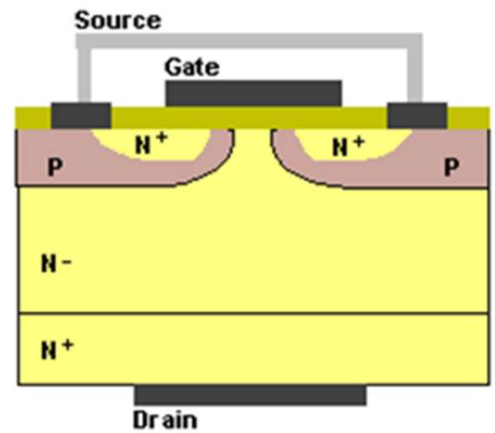
Power MOSFET

- The Power MOSFET is a type of MOSFET. The operating principle of power MOSFET is similar to the general MOSFET.
- The power MOSFETS are very special to handle the **high level of powers**.
- It shows the **high switching speed** and by comparing with the normal MOSFET, the power MOSFET will work better.
- The power MOSFETs is widely used in the n-channel enhancement mode, p-channel enhancement mode, and n-channel depletion mode, p-channel depletion mode.

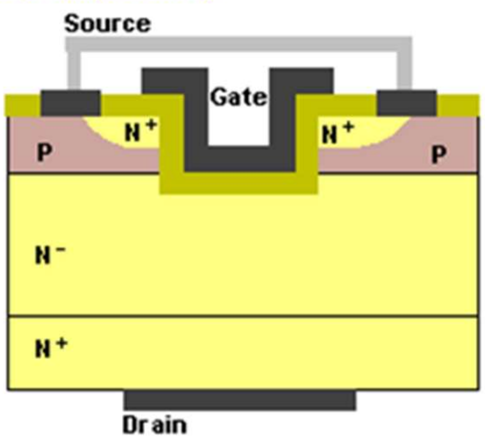
VMOS (V-Shaped MOS)



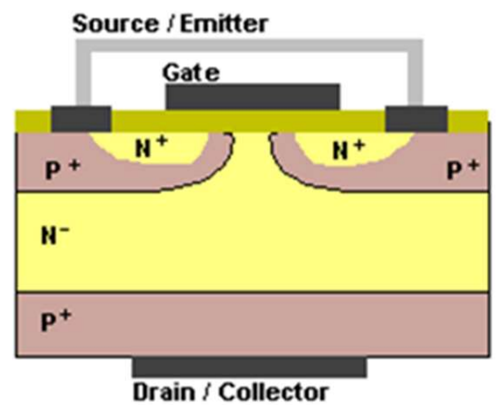
DMOS (Double-Diffused MOS)



UMOS (U-Shaped MOS)

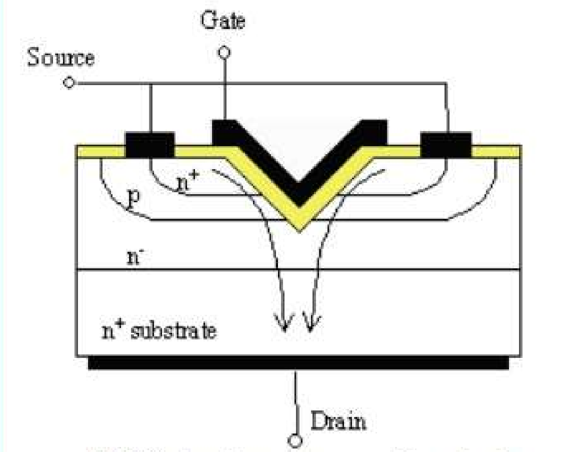


IGBT (Insulated Gate Bipolar Transistor)



VMOS

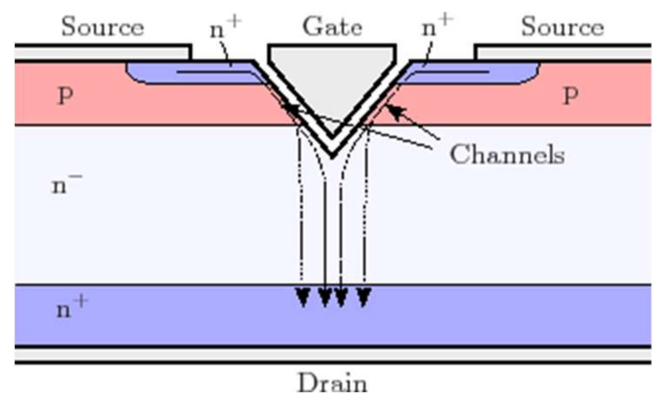
- VMOS stands for **Vertical Metal Oxide Silicon**.
- The device has V-shaped gate region.
- Vertical MOSFET with high current handling capability as well as high blocking voltage.
- Vertical structure allows for use of low-doped **drain region** which results in a high blocking voltage.



VMOS structure (cross section view)

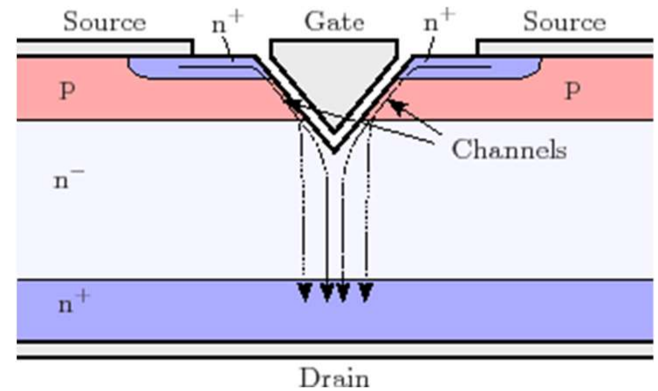
VMOS

- It consists of a **double diffused n+/p layer**, cut by a V-shaped groove.
- The gate consists of metallized area over the V groove which controls current flow in P-region.
- V-grove cut through the double diffused layer creating two vertical MOSFETs.
- Due to source at top and drain at bottom, the **current flows vertically** rather than horizontally.
- V shape allows device to deliver **higher** amount of **current** from source to the drain.



VMOS

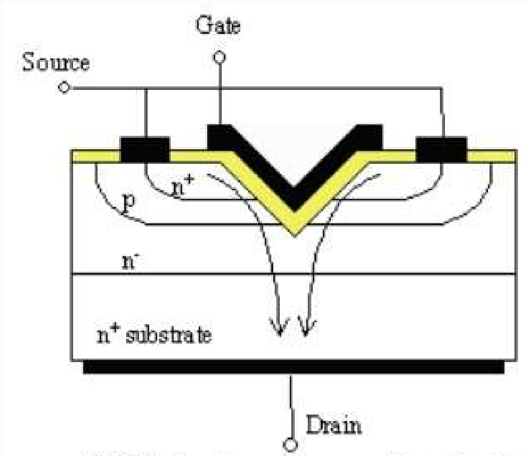
- V shape of the depletion region creates a **wider channel**.
- The V shaped gate makes **cross-sectional area** of source to drain path **larger**.
- Hence **lower ON resistance** of the device can be achieved which allows much higher power.
- VMOS structure is more complex compare to traditional FET device. This makes it more expensive.



Application of VMOS

The devices are used for applications requiring medium powers such as

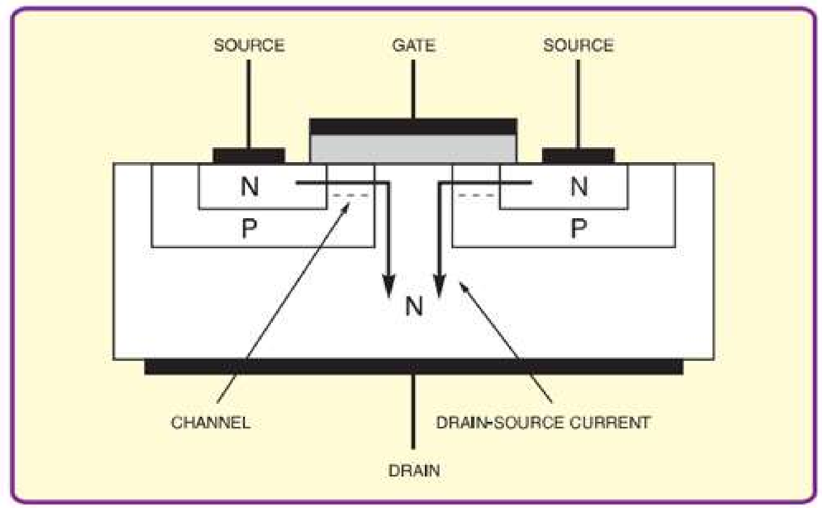
- Hi-Fi audio power amplifiers
- Broadband high frequency amplifiers
- Switching power amplifiers.



VMOS structure (cross section view)

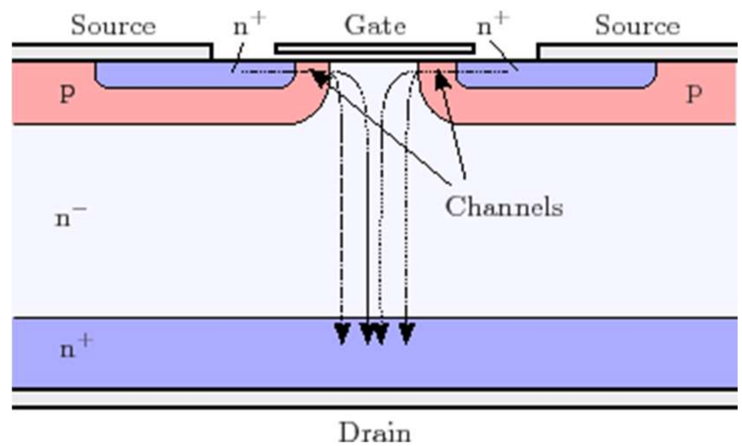
DMOS

- DMOS stands for **Double-Diffused MOS**.
- A power MOSFET in which the source and channel region are formed using a double diffusion process.
- The device is widely used in switching applications requiring **high voltage and high frequency** behavior.



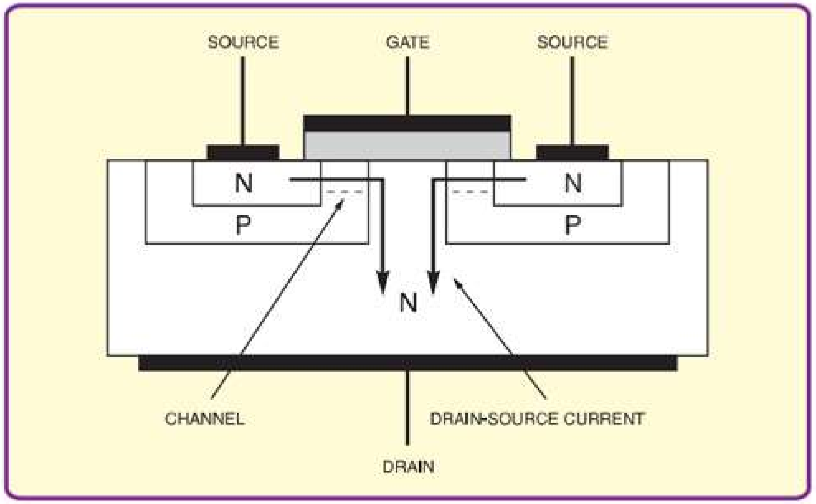
DMOS

- The DMOS device uses a double diffusion process.
- The p-region and the n+ source regions are diffused through common window. This is defined by edge of the gate.
- The p-region is being diffused deeper compare to n+ source.
- The surface channel length is defined as the lateral diffusion distance between the p-substrate and the n+ source.



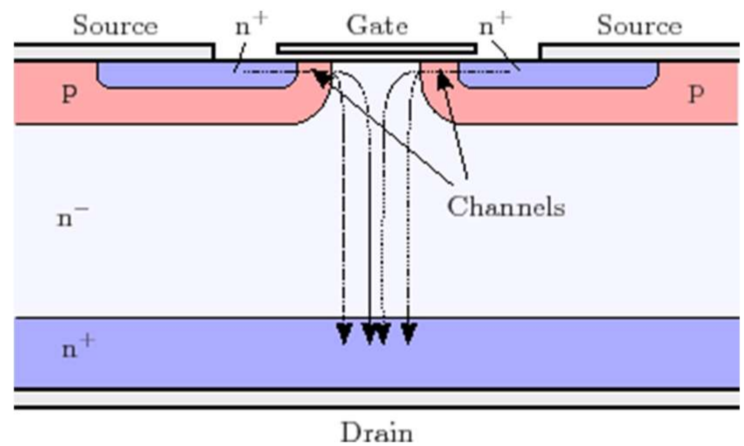
DMOS

- Electrons enter the source terminal and flow laterally through the inversion layer under the gate to the n-drift region.
- Once here, the electrons flow vertically through the n-drift region to the drain terminal.
- Conventional current direction is from the drain to the source.



DMOS

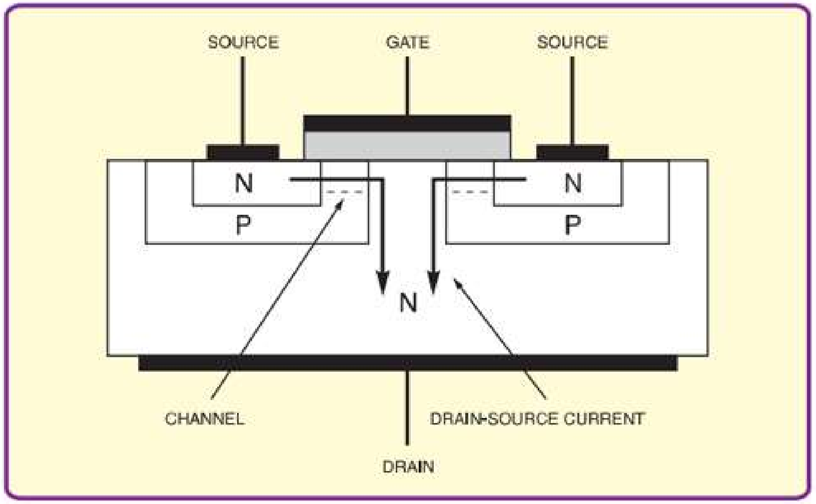
- The breakdown voltage and on-resistance are two important parameters of DMOS device.
- Due to high voltage and high frequency characteristics it is similar to BJT.
- The very **high breakdown voltage** is achieved due to lightly doped drift region between Drain and channel regions.
- The **n-drift region thickness** should be as **thin** as possible in order to achieve **lower drain resistance**.



Application of DMOS

The applications of DMOS are

- Inkjet printheads,
- automobile control electronics,
- power supplies etc.



Summary

- Power MOSFETs have vertical structure of both the VMOS and DMOS.
- Used in a variety of applications that desire increased switching speeds and a variety of voltage levels.
- Doping and channel lengths contribute to the characteristics of each of these MOSFETs.