SCHOOL OF COMPUTING

DEPARTMENT OF COMPUTER SCIENCE & ENGINEERING

DEPARTMENT OF INFORMATION TECHNOLOGY

Electrical and Electronics Engineering – SEEA1103
UNIT – IV
SEMICONDUCTOR DEVICES

SEMICONDUCTOR DEVICES

Characteristics of PN-junction diodes and Zener diodes, BJT and its configurations – input/output Characteristics, Junction Field Effect Transistor – Drain and Transfer Characteristics, MOSFET – Depletion type and Enhancement type, Uni Junction Transistors - Silicon Controlled Rectifiers.

CLASSIFICATION OF MATERIALS :

Materials can be classified based on its conductivity property as:

Conductor: A conductor is a material which allows free flow of charge when a voltage is applied across its terminals. i.e. it has very high conductivity. Eg: Copper, Aluminum, Silver, Gold.
Semiconductor: A semiconductor is a material that has its conductivity somewhere between the insulator and conductor. The resistivity level is in the range of 10 and 104 Ω-cm. Eg: Silicon and Germanium. Both have 4 valance electrons. Electronic devices like PN diode, Zener diode Bipolar Junction Transistor are made using these semiconductors.
Insulator: An insulator is a material that offers a very low level (or negligible) of conductivity when voltage is applied. Eg: Paper, Mica, glass, quartz.

Classification of semiconductors

- **Intrinsic semiconductor**
- **Extrinsic semiconductor**

Intrinsic semiconductor
They are semi-conducting materials which are pure and no impurity atoms are added to it. Eg: Germanium and Silicon.

Properties:

- **Number of electrons is equal to the number of holes. I.e., ne=nh.**
- **Electrical conductivity is low.**
- **Electrical conductivity of intrinsic semiconductors depends on their temperatures.**

Extrinsic semiconductors
Intrinsic semiconductor has very limited applications as they conduct very small amounts of current at room temperature. The current conduction capability of intrinsic semiconductor can be increased significantly by adding a small amounts impurity to the intrinsic semiconductor. By adding impurities it becomes impure or extrinsic semiconductor. This process of adding impurities is called as doping. The amount of impurity added is 1 part in 106 atoms

Properties:

- **The number of electrons is not equal to the number of holes.**
- **The electrical conductivity is high.**
- **The electrical conductivity depends on the temperature and the amount of impurity added in them. They are further subdivided as**
  - **P type semiconductor**
  - **N type semiconductor**

P type semiconductor:

When a intrinsic semiconductor is added with Trivalent impurity it becomes a P- Type semiconductor. Examples of trivalent impurities are Boron, Gallium, indium etc.

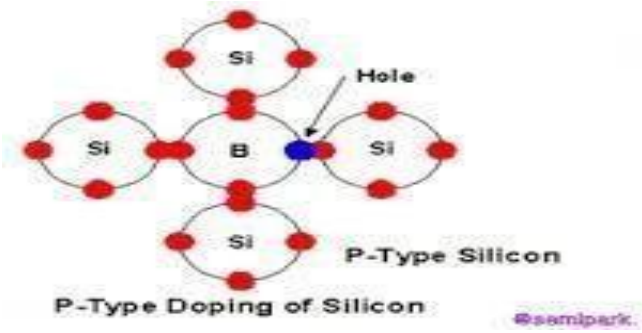


Fig. 4.1 P type Semiconductor

The crystal structure of P type semiconductor is shown in the Fig. 4.1. The three valance electrons of the impurity (boron).

forms three covalent bonds with the neighboring atoms and a vacancy exists in the fourth bond giving rise to the holes. The hole is ready to accept an electron from the neighboring atoms. Each trivalent atom contributes to one hole generation and thus introduces a large no. of holes in the valance band. At the same time the no. electrons are decreased compared to those available in intrinsic semiconductor because of increased recombination due to creation of additional holes. Thus in P type semiconductor,

- **Holes are majority carriers and electrons are minority carriers.**
- **The semiconductor is rich in holes.**

N type semiconductor:

If the added impurity is a pentavalent atom then the resultant semiconductor is called N-type semiconductor. Examples of pentavalent impurities are Phosphorus, Arsenic, Bismuth, Antimony etc.

A pentavalent impurity has five valance electrons. Fig 4.2 shows the crystal structure of N type semiconductor material where four out of five valance electrons of the impurity atom(antimony) forms covalent bond with the four intrinsic semiconductor atoms. The fifth electron is loosely bound to the impurity atom. This loosely bound electron can be easily excited from the valance band to the conduction band by the application of electric field or increasing the thermal energy. The energy required to detach the fifth electron form the impurity atom is very small of the order of 0.01ev for Ge and 0.05 eV for Si. Thus in a N type semiconductor

- **Electrons are majority carriers and holes are minority carriers.**
- **The semiconductor is rich in electrons.**

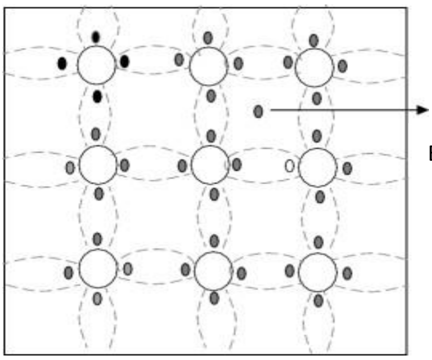


Fig. 4.2 N type Semiconductor

PN JUNCTION THEORY

When P and N type semiconductors are fused together, we obtain PN junction. When first joined together, very large density gradient exists between both sides of the PN junction. Therefore at the junction there is a tendency of free electrons from N side to diffuse over to the P side and the holes to the N side. This process is called diffusion. Hence some of the free electrons from the N side begin to migrate across this newly formed junction to fill up the holes in the P- type material.

As the free electrons move across the junction from N type to P type, they leave behind positively charge (donor ions) on the negative side and hence a positive charge is built on the N-side of the junction. Similarly, the holes from the P side migrate across the junction in the opposite direction into the N region where there are large numbers of free electrons. As a result, the charge density of the P-type along the junction is filled with negatively charged acceptor ions, and hence a negative charge is built on the P-side of the junction. The width of these layers depends on how heavily each side is doped with acceptor density and donor density respectively.

The electrostatic field across the junction caused by the positively charged N-Type region tends to drive the holes away from the junction and negatively charged P type regions tend to drive the electrons away from the junction. Thus near the junction, a region depleted of mobile charge carriers is formed. This is called depletion layer, space region, and transition region. The depletion region is of the order of 0.5μm thick. There are no mobile carriers in this narrow depletion region. Hence no current flows across the junction and the system is in equilibrium.

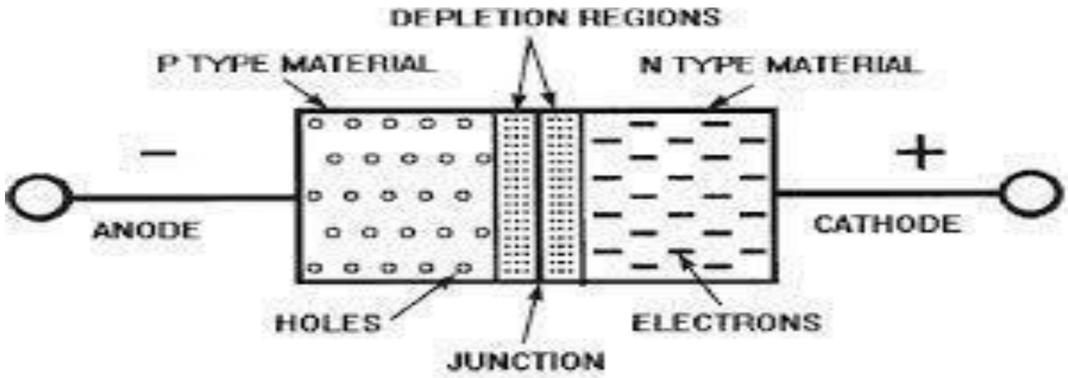


Fig. 4.3 PN junction

FORWARD BIASED OPERATION

When external voltage is applied then the potential difference is altered between the P and N regions. Positive terminal of the source is connected to the P side and the negative terminal is connected to N side then the PN junction diode is said to be connected in forward bias condition. This lowers the potential across the junction. The majority charge carriers in N and P regions are attracted towards the PN junction and the width of the depletion layer decreases with diffusion of the majority

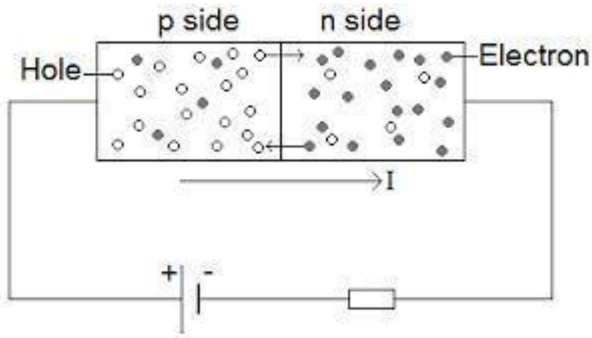


Fig. 4.4 Forward bias PN junction diode

charge carriers. The external biasing causes a departure from the state of equilibrium and also in the depletion layer. With the increase in forward bias greater than the built in potential, at a particular value the depletion region becomes very much thinner so that a large number of majority charge carriers can cross the PN junction and conducts an electric current. The current flowing up to built in potential is called as ZERO current or KNEE current.

4.2.3.Reverse Bias Operation

Positive terminal of the source is connected to the N side and the negative terminal is connected to P side. Here majority charge carriers are attracted away from the depletion layer by their respective battery terminals connected to PN junction. Positive terminal attracts the electrons away from the junction in N side and negative terminal attracts the holes away from the junction in P side. As a result of it, the width of the potential barrier increases that impedes the flow of majority carriers in N side and P side. The width of the free space charge layer increases, thereby electric field at the PN junction increases and the PN junction diode acts as a resistor. The current that flows in a PN junction diode is the small leakage current, due to minority carriers generated at the depletion layer or minority carriers which drift across the PN junction. The growth in the width of the depletion layer presents a high impedance path which acts as an insulator.

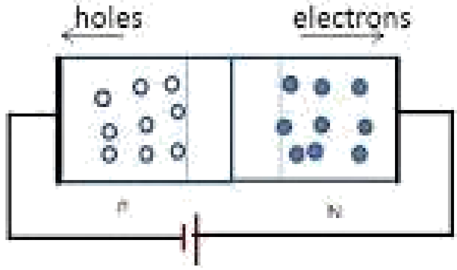


Fig. 4.5 Reverse bias PN junction diode

4.2.4 .VI characteristics of PN Diode

The VI characteristics of PN junction diode in forward bias are non linear, that is, not a straight line. This nonlinear characteristic illustrates that during the operation of the PN junction, the resistance is not constant. The slope of the PN junction diode in forward bias shows the resistance is very low. When forward bias is applied to the diode if this external voltage becomes greater than the value of the potential barrier, approx. 0.7 volts for silicon and 0.3 volts for germanium, then it causes a low impedance path and permits to conduct a large amount of current. Thus the current starts to flow above the knee point with a small amount of external potential.

In reverse bias condition, the P-type of the PN junction is connected to the negative terminal and N-type is connected to the positive terminal of the external voltage. This results in increased potential barrier at the junction. Hence, the junction resistance becomes very high and as a result practically no current flows through the circuit. However, a very small current of the order of µA, flows through the circuit in practice. This is knows as reverse saturation current and it is due to the minority carriers in the junction.

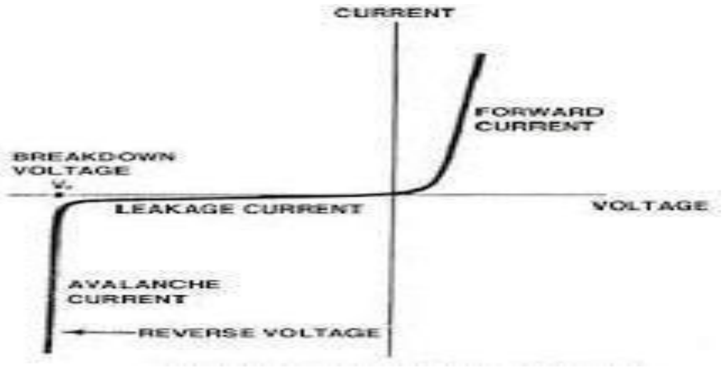


Fig. 4.6 VI characteristics of PN Diode

Applications of PN junction Diode:

The P-N junction diode has many applications.

- **P-N junction diode in reverse biased configuration is sensitive to light from a range between 400nm to 1000nm, which includes VISIBLE light. Therefore, it can be used as a photodiode.**
- **It can also be used as a solar cell.**
- **P-N junction forward bias condition is used in all LED lighting applications.**
- **The voltage across the P-N junction biased is used to create Temperature Sensors, and Reference voltages.**
- **It is used in many circuits" rectifiers, varactor for voltage controlled oscillators.**

ZENER DIODE:

A zener diode is a special type of device designed to operate in the zener breakdown region which is heavily doped than the normal PN junction diode. Hence, it has very thin depletion region. Therefore, Zener diode allow more electric current than the normal PN junction diodes under forward bias like a normal diode but also allows electric current in the reverse direction if the applied reverse voltage is greater than the zener voltage. Thus they are always connected in reverse direction because it is specifically designed to work in reverse direction. The breakdown voltage of a Zener diode is carefully set by controlling the doping level during manufacture. The name Zener diode was named after the American physicist Clarance Melvin Zener who discovered the zener effect.

Diode symbol

Breakdown in Zener diode

There are two types of reverse breakdown regions in a Zener diode: Avalanche breakdown and Zener breakdown.

Avalanche breakdown

The avalanche breakdown occurs at high reverse voltage. When high reverse voltage is applied to the diode, the free electrons gains large amount of energy and accelerated to greater velocities. The free electrons moving at high speed will collides with the atoms and knock off more electrons. These electrons are again accelerated and collide with other atoms. Because of this continuous collision with the atoms, a large number of free electrons are generated. This cumulative process is referred to as avalanche multiplication which results in the flow of large reverse current and this breakdown of the diode is called avalanche breakdown. Avalanche breakdown occurs in zener diodes with zener voltage greater than 6V.

Zener breakdown:

The zener breakdown occurs in heavily doped diodes because of their narrow depletion region. When reverse biased voltage applied to the diode is increased, the narrow depletion region generates strong electric field. When it reaches close to zener voltage, the electric field in the depletion region is strong enough to pull electrons from their valence band. The valence electrons which gains sufficient energy from the strong electric field of depletion region will breaks bonding with the parent atom. The valance electrons which break bonding with parent atom will become free electrons. This free electrons results in large electric current, a small increase in voltage will rapidly increases the electric current. This breakdown is referred to as Zener breakdown.

Note:

- Zener breakdown occurs at low reverse voltage whereas avalanche breakdown occurs at high reverse voltage.
- Zener breakdown occurs in Zener diodes because they have very thin depletion region.
- Breakdown region is the normal operating region for a zener diode.
- Zener breakdown occurs in Zener diodes with Zener voltage less than 6V.

ZENER DIODE CHARACTERISTICS:

When a Zener diode is biased in the forward direction it behaves just like a normal PN junction diode.

Under reverse-biased condition, the reverse voltage is applied. As the reverse bias voltage is increased, breakdown of the junction occurs. The breakdown voltage depends upon the amount of doping. If the diode is heavily doped, depletion layer will be thin and consequently, breakdown occurs at lower reverse voltage and further, the breakdown voltage is sharp. A lightly doped diode has a higher breakdown voltage. Thus breakdown voltage can be selected with the amount of doping .This breakdown voltage point is called the "Zener voltage or breakdown voltage " and a large amount of current flows through the Zener diodes. This Zener breakdown voltage on the I-V curve is almost a vertical straight line.

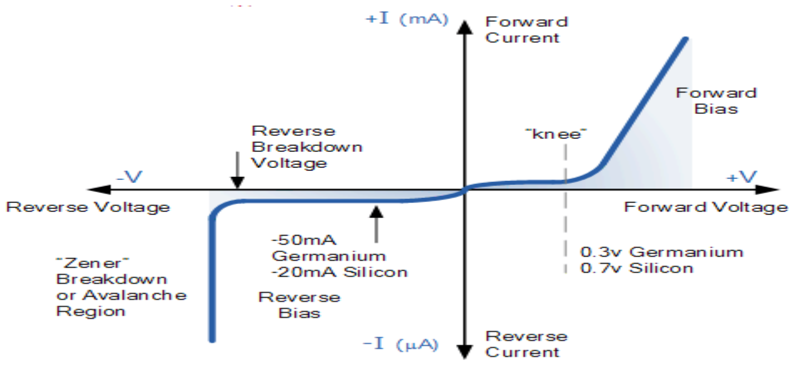


Fig. 4.7 VI characteristics of Zener diode ZENER DIODE AS A VOLTAGE

REGULATOR

From the Zener Characteristics shown, under reverse bias condition, the voltage across the diode remains constant although the current through the diode increases as shown. Thus the voltage across the zener diode serves as a reference voltage. Hence the diode can be used as a voltage regulator.

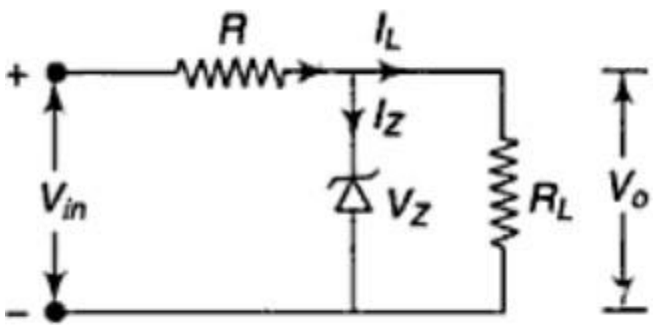


Fig. 4.8 Voltage regulator

It is required to provide constant voltage across load resistance RL , whereas the input voltage may be varying over a range. As shown, Zener diode is reverse biased and as long as the input voltage does not fall below Zener breakdown voltage, the voltage across the diode will be constant and hence the load voltage will also be constant.

BIPOLAR JUNCTION TRANSISTOR INTRODUCTION

The transistor was developed by Dr. Shockley along with Bell Laboratories team in 1951. It is a three terminal device whose output current, voltage and power are controlled by its input current. In communication systems it is the primary component in the amplifier. The important property of the transistor is that it can raise the strength of a weak signal. This property is called amplification. Transistors are used in digital computers, satellites, mobile phones and other communication systems, control systems etc., A transistor consists of two P-N junction. The junction are formed by sand witching either p-type or n-type semiconductor layers between a pair of opposite types which is shown below

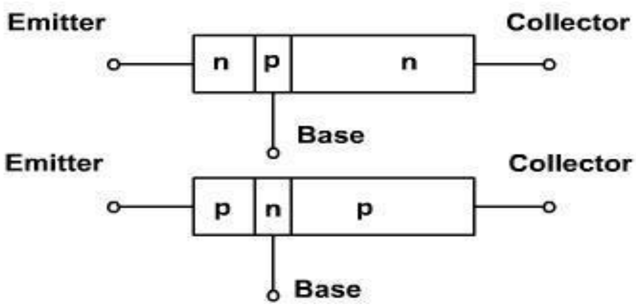


Fig. 4.9 Transistor

TRANSISTOR CONSTRUCTION:

A transistor has three regions known as emitter, base and collector.
Emitter:

- **It is a region situated in one side of a transistor, which supplies charge carriers (ie., electrons and holes) to the other two regions**
- **Emitter is heavily doped region**

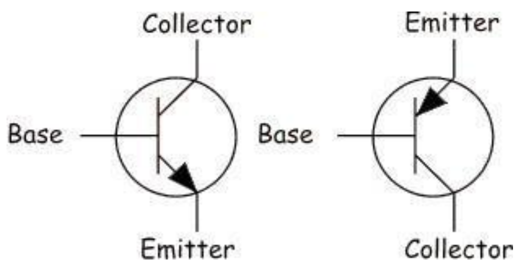
Base:

- **It is the middle region that forms two P-N junction in the transistor**
- **The base of the transistor is thin as compared to the emitter and is a lightly doped region**

Collector:

- **It is a region situated in the other side of a transistor (ie., side opposite to the emitter) which collects the charge carriers.**
- **The collector of the transistor is always larger than the emitter and base of a transistor**
- **The doping level of the collector is intermediate between the heavy doping of emitter and the light doping of the base.**

TRANSISTOR SYMBOLS



NPN Transistor **PNP transistor**

Fig. 4.10 Transistor

- **The transistor symbol carries an arrow head in the emitter pointing from the P-**

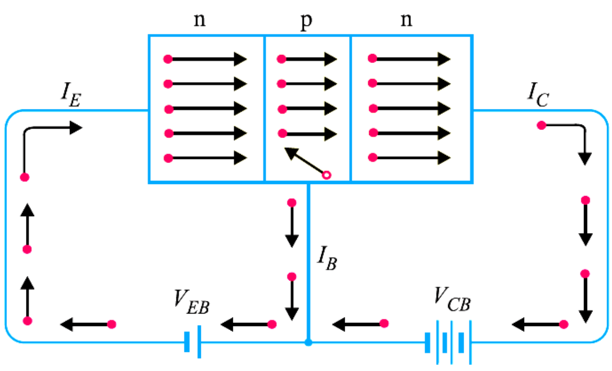
region towards the N- region

- The arrow head indicates the direction of a conventional current flow in a transistor.
- The direction of arrow heads at the emitter in NPN and PNP transistor is opposite to each other.
- The PNP transistor is a complement of the NPN transistor.
- In NPN transistor the majority carriers are free electrons, while in PNP transistor these are the holes.

UNBIASED TRANSISTORS

A transistor with three terminals (Emitter, Base, Collector) left open is called an unbiased transistor or an open – circuited transistor. The diffusion of free electrons across the junction produces two depletion layers. The barrier potential of three layers is approximately 0.7v for silicon transistor and 0.3v for germanium transistor. Since the regions have different doping levels therefore the layers do not have the same width. The emitter base depletion layer penetrates slightly into the emitter as it is a heavily doped region where as it penetrates deeply into the base as it is a lightly doped region. Similarly the collector- base depletion layer penetrates more into the base region and less into the collector region. The emitter- base depletion layer width is smaller than that of collector base depletion layer. The unbiased transistor is never used in actual practice. Because of this we went for transistor biasing.

OPERATION OF NPN TRANSISTOR



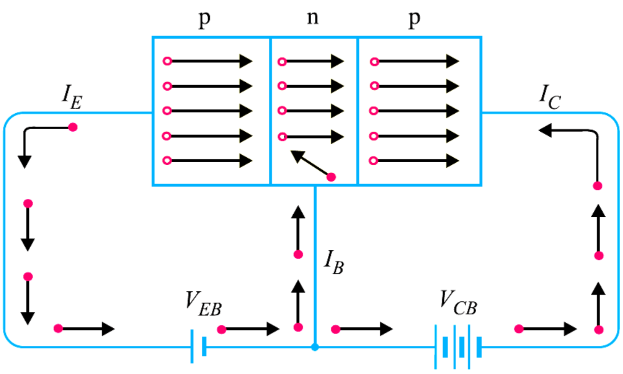
Basic connection of *npn* transistor

Fig. 4.11 NPN Transistor

- The NPN transistor is biased in forward active mode ie., emitter – base of transistor is forward biased and collector base junction is reverse biased
- The emitter – base junction is forward biased only if V is greater than barrier potential which is 0.7v for silicon and 0.3v for germanium transistor
- The forward bias on the emitter- base junction causes the free electrons in the N – type emitter to flow towards the base region. This constitutes the emitter current (IE). Direction of conventional current is opposite to the flow of electrons.
- Electrons after reaching the base region tend to combine with the holes.
- If these free electrons combine with holes in the base, they constitute base current (IB).
- Most of the free electrons do not combine with the holes in the base.
- This is because of the fact that the base and the width is made extremely small and electrons do not get sufficient holes for recombination.

- Thus most of the electrons will diffuse to the collector region and constitutes collector current (IC). This collector current is also called injected current, because of this current is produced due to electrons injected from the emitter region
- There is another component of collector current due to the thermal generated carriers.
- This is called as reverse saturation current and is quite small.

OPERATION OF PNP TRANSISTOR



Basic connection of *pnp* transistor

Fig. 4.12 PNP Transistor

- Operation of a PNP transistor is similar to npn transistor
- The current within the PNP transistor is due to the movement of holes where as, in an NPN transistor it is due to the movement of free electrons
- In PNP transistor, its emitter – base junction is forward biased and collector base junction is reverse biased.
- The forward bias on the emitter – base junction causes the holes in the emitter region to flow towards the base region
- This constitutes the emitter current (IE).
- The holes after reaching the base region combine with the electrons in the base and constitute base current (IB).
- Most of the holes do not combine with the electrons in the base region
- This is due to the fact that base width is made extremely small, and holes does not get sufficient electrons for recombination.
- Thus most of the holes diffuse to the collector region and constitutes collector current (IC).
- This current is called injected current, because it is produced due to the holes injected from the emitter region
- There is small component of collector current due to the thermally generated carriers
- This is also called as reverse saturation current.

TRANSISTOR CONFIGURATIONS

- A transistor is a three terminal device, but we require four terminals (two for input and two for output) for connecting it in a circuit.
- Hence one of the terminal is made common to the input and output circuits.
- The common terminal is grounded.

- **There are three types of configuration for the operation of a transistor.**

Common base configuration

- **This is also called grounded base configuration**
- **In this configuration emitter is the input terminal, collector is the output terminal and base is the common terminal**

Common emitter configuration(CE)

- **This is also called grounded emitter configuration**
- **In this configuration base is the input terminal, collector is the output terminal and emitter is the common terminal**

Common collector configuration(CC)

- **This is also called grounded collector configuration**
- **In this configuration, base is the input terminal, emitter is the output terminal and collector is the common terminal.**

COMMON BASE CONFIGURATION (CB)

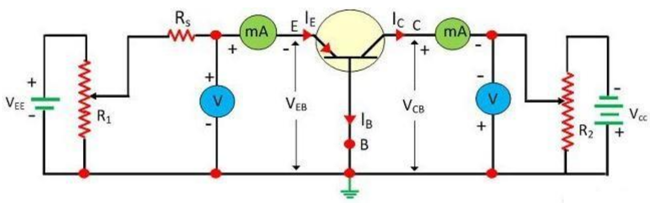


Fig. 4.13 CB Configuration

- **The input is connected between emitter and base and output is connected across collector and base**
- **The emitter – base junction is forward biased and collector – base junction is reverse biased.**
- **The emitter current, flows in the input circuit and the collector current flows in the output circuit.**
- **The ratio of the collector current to the emitter current is called current amplification factor.**

CHARACTERISTICS OF CB CONFIGURATION

- **The performance of transistors determined from their characteristic curves that relate different d.c currents and voltages of a transistor**
- **Such curves are known as static characteristics curves There are two important characteristics of a transistor**

➢ **Input characteristics**
➢ **Output characteristics**

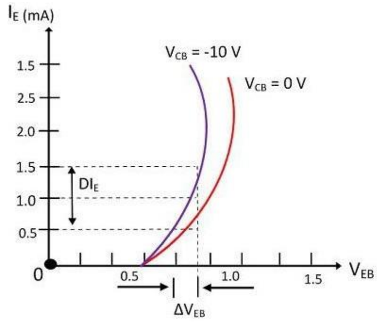


Fig. 4.14 Characteristics of CB Configuration

INPUT CHARACTERISTICS

The curve drawn between emitter current and emitter – base voltage for a given value of collector – base voltage is known as input Characteristic curves.

The following points are taken into consideration from the characteristic curve.

- **For a specific value of VCB, the curve is a diode characteristic in the forward region. The PN emitter junction is forward biased.**
- **When the value of the voltage base current increases the value of emitter current increases slightly. The junction behaves like a better diode. The emitter and collector current is independent of the collector base voltage VCB.**
- **The emitter current IE increases with the small increase in emitter-base voltage VEB. It shows that input resistance is small.**

Input Resistance

The ratio of change in emitter-base voltage to the resulting change in emitter current at constant collector base voltage VCB is known as $r_i = \frac{\Delta V_{EB}}{\Delta I_E}$ **input resistance. The input resistance is expressed by the formula.**

Base width modulation (or) Early effect

- **In a transistor, since the emitter – base junction is forward biased there is no effect on the width of the depletion region.**
- **However, since collector – base junction is reverse biased, as the reverse bias voltage across the collector – base junction increases the width of the depletion region also increases.**
- **Since the base is lightly doped the depletion region penetrates deeper into the base region.**
- **This reduces the effective width of the base region.**
- **This variation or modulation of the effective base width by the collector – base voltage is known as base width modulation or early effect.**

The decrease in base width by the collector voltage has the following three effects

- **It reduces the chances of recombination of electrons with the holes in the** base region. Hence current gain increases with increase in collector – base voltage.

- The concentration gradient of minority carriers within the base increases. This increases the emitter current.
- For extremely collector voltage, the effective base width may be reduced to zero, resulting in voltage breakdown of a transistor. This phenomenon is known as punch through.

Output characteristics

The curve drawn between collector current and collector – base voltage, for a given value of emitter current is known as output characteristics.

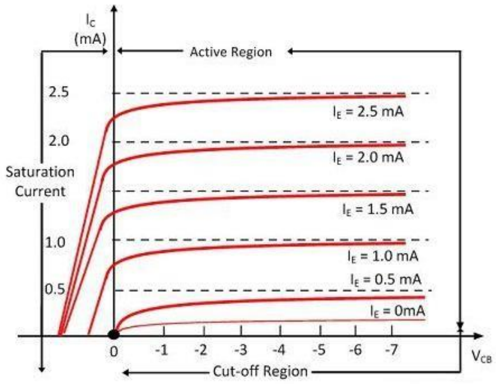


Fig. 4.15 Characteristics of CB Configuration

- The active region of the collector-base junction is reverse biased, the collector current IC is almost equal to the emitter current IE. The transistor is always operated in this region.
- The curve of the active regions is almost flat. The large charges in VCB produce only a tiny change in IC. The circuit has very high output resistance ro.
- When VCB is positive, the collector-base junction is forward bias and the collector current decrease suddenly. This is the saturation state in which the collector current does not depend on the emitter current.
- When the emitter current is zero, the collector current is not zero. The current which flows through the circuit is the reverse leakage current, i.e., ICBO. The current is temperature depends and its value range from 0.1 to 1.0 µA for silicon transistor and 2 to 5 µA for germanium transistor.

Output Resistance

$$r_0 = \frac{\Delta V_{CB}}{\Delta I_C}$$

The ratio of change in collector-base voltage to the change in collector current at constant emitter current IE is known as output resistance.

COMMON – EMITTER CONFIGURATION

- The input is connected between base and emitter, while output is connected between collector and emitter
- Emitter is common to both input and output circuits.
- The bias voltage applied are Vce and Vbe.
- The emitter-base junction is forward biased and collector-emitter junction is reverse biased.
- The base current Ib flows in the input circuit and collector current Ic flows sin the output circuit.

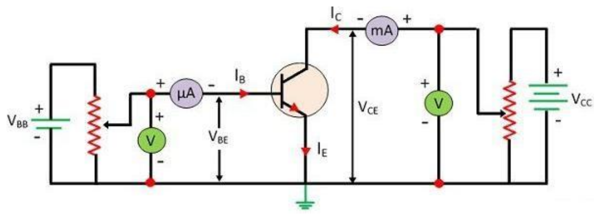


Fig. 4.16 CE Configuration

INPUT CHARACTERISTICS

- The curve plotted between base current IB and the base-emitter voltage VEB is called Input characteristics curve.
- For drawing the input characteristic the reading of base currents is taken through the ammeter on emitter voltage VBE at constant collector-emitter current.
- The curve for different value of collector-base current is shown in the figure below.

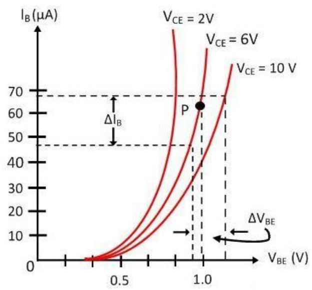


Fig. 4.17 Characteristics of CE Configuration

- The curve for common Emitter configuration is similar to a forward diode characteristic.
- The base current IB increases with the increases in the emitter-base voltage VBE. Thus the input resistance of the CE configuration is comparatively higher that of CB configuration.
- The effect of CE does not cause large deviation on the curves, and hence the effect of a change in VCE on the input characteristic is ignored.

Input Resistance:

The ratio of change in base-emitter voltage VBE to the change in base current ΔIB at constant collector-emitter voltage VCE is known as input resistance, i.e.,

$$r_i = \frac{\Delta V_{BE}}{\Delta I_B} \text{ at constant } V_{CE}$$

OUTPUT CHARACTERISTIC

In CE configuration the curve draws between collector current IC and collector-emitter voltage VCE at a constant base current IB is called output characteristic. The characteristic curve for the typical NPN transistor in CE configuration is shown in the figure below.

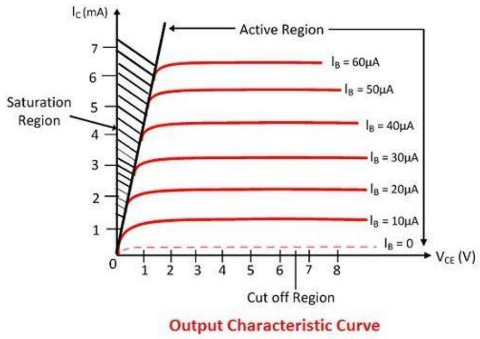


Fig. 4.18 Characteristics of CE Configuration

- **In the active region, the collector current increases slightly as collector-emitter VCE current increases. The slope of the curve is quite more than the output characteristic of CB configuration. The output resistance of the common base connection is more than that of CE connection.**
- **The value of the collector current IC increases with the increase in VCE at constant voltage IB, the value β of also increases.**
- **When the VCE falls, the IC also decreases rapidly. The collector-base junction of the transistor always in forward bias and work saturate. In the saturation region, the collector current becomes independent and free from the input current IB**
- **In the active region IC = βIB, a small current IC is not zero, and it is equal to reverse leakage current ICEO.**

Output Resistance:

The ratio of the variation in collector-emitter voltage to the collector-emitter current is known at collector currents at a constant base current IB is called output resistance ro.

$$r_o = \frac{\Delta V_{CE}}{\Delta I_C} \text{ at constant } I_B$$

The value of output resistance of CE configuration is more than that of CB.

COMMON - COLLECTOR CONFIGURATION

The configuration in which the collector is common between emitter and base is known as

CC configuration. In CC configuration, the input circuit is connected between emitter and base and the output is taken from the collector and emitter. The collector is common to both the input and output circuit and hence the name common collector connection or common collector configuration.

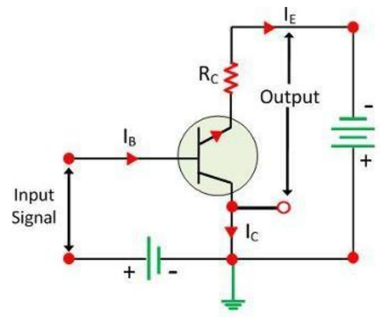


Fig. 4.19 CB Configuration

INPUT CHARACTERISTICS

The input characteristic of the common collector configuration is drawn between collector base voltage VCE and base current IB at constant emitter current voltage VCE. The value of the output voltage VCE changes with respect to the input voltage VBC and IB With the help of these values, input characteristic curve is drawn. The input characteristic curve is shown below.

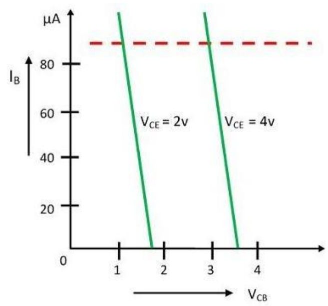


Fig. 4.20 Input Characteristics of CC Configuration

OUTPUT CHARACTERISTICS

The output characteristic of the common emitter circuit is drawn between the emitter-collector voltage VEC and output current IE at constant input current IB. If the input current IB is zero, then the collector current also becomes zero, and no current flows through the transistor.

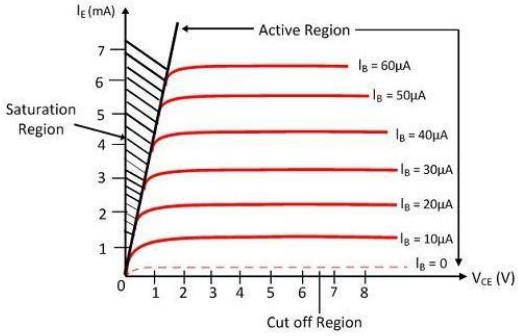


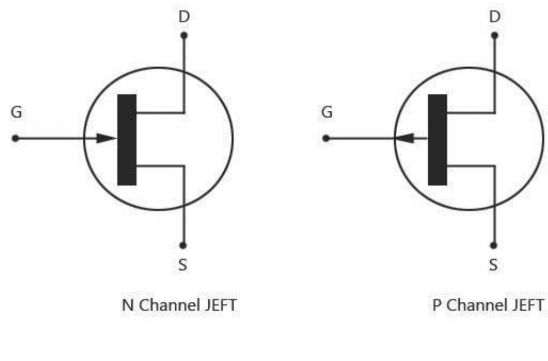
Fig. 4.21 Output Characteristics of CC Configuration

The transistor operates in active region when the base current increases and reaches to saturation region. The graph is plotted by keeping the base current IB constant and varying the emitter-collector voltage VCE, the values of output current IE are noticed with respect to VCE. By using the VCE and IE at constant IB the output characteristic curve is drawn.

JUNCTION FIELD EFFECT TRANSISTOR (JFET)

JFET is a unipolar-transistor, which acts as a voltage controlled current device and is a device in which current at two electrodes is controlled by the action of an electric field at a PN junction.

A JFET, or junction field-effect transistor, or JUGFET, is a FET in which the gate is created by reverse-biased junction (as opposed to the MOSFET which creates a junction via a field generated by conductive gate, separated from the gate region by a thin insulator).



JFET-N-Channel and P-channel Schematic Symbol

Fig. 4.22 JFET

CONSTRUCTION

N-Channel JFET

The figure shows construction and symbol of N-channel JFET. A small bar of extrinsic semiconductor material, N type is taken and its two ends, two ohmic contacts are made which is the drain and source terminals of FET.

Heavily doped electrodes of P type material form PN junctions on each side of the bar. The thin region between the two P gates is called the channel. Since this channel is in the N type bar, the FET is known as N-channel JFET.

The electrons enter the channel through the terminal called source and leave through the terminal called drain. The terminals taken out from heavily doped electronics of P type material are called gates. These electrodes are connected together and only one terminal is taken out, which is called gate, as shown below.

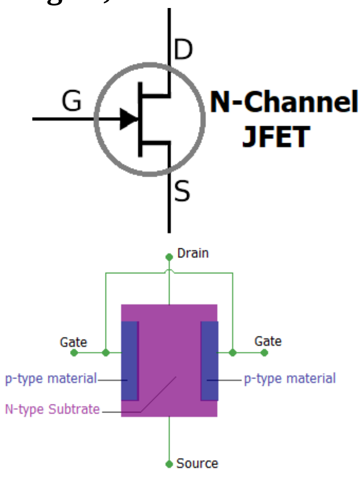


Fig. 4.23 N-Channel JFET

P-Channel JFET

The device could be made of P type bar with two N type gates as shown in the figure below. This will be P- channel JFET. The principle of working of N-channel JFET

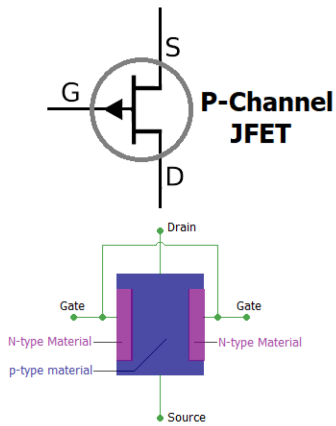


Fig. 4.24 P-Channel JFET

and P-channel JFET are similar. The only difference being that in N-channel JFET the current is carried by electrons while in P-channel JFET, it is carried by holes.

WORKING OF JFET

One best example to understand the working of a JFET is to imagine the garden hose pipe. Suppose a garden hose is providing a water flow through it. If we squeeze the hose the water flow will be less and at a certain point if we squeeze it completely there will be zero water

flow. JFET works exactly in that way. If we interchange the hose with a JFET and the water flow with a current and then construct the current-carrying channel, we could control the current flow.

When there is no voltage across gate and source, the channel becomes a smooth path which is wide open for electrons to flow. But the reverse thing happens when a voltage is applied between gate and source in reverse polarity, which makes the P-N junction, reversed biased and makes the channel narrower by increasing the depletion layer and could put the JFET in cut-off or pinch off region.

In the below image we can see the saturation mode and pinch off mode and we will be

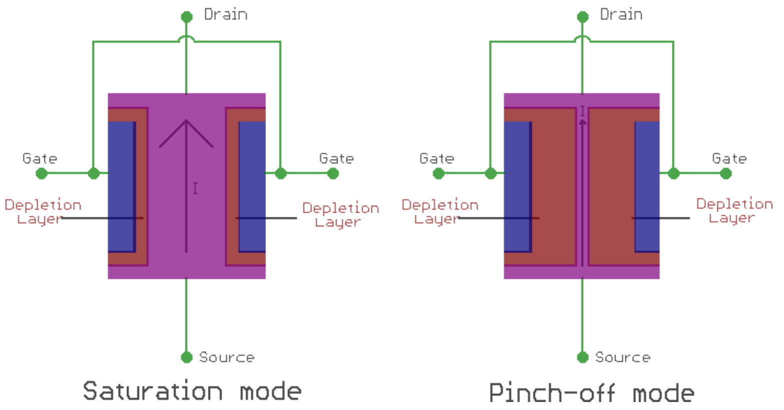


Fig. 4.25 Operation of JFET

able to understand the depletion layer became wider and the current flow becomes less.If we want to switch off a JFET we need to provide a negative gate to source voltage denoted as VGS for an N-type JFET. For a P-type JFET, we need to provide positive VGS.

JFET only works in the depletion mode.

CHARACTERISTICS OF JFETS

There are two types of static characteristics viz

1. **Output or drain characteristics and**
2. **Transfer characteristic.**

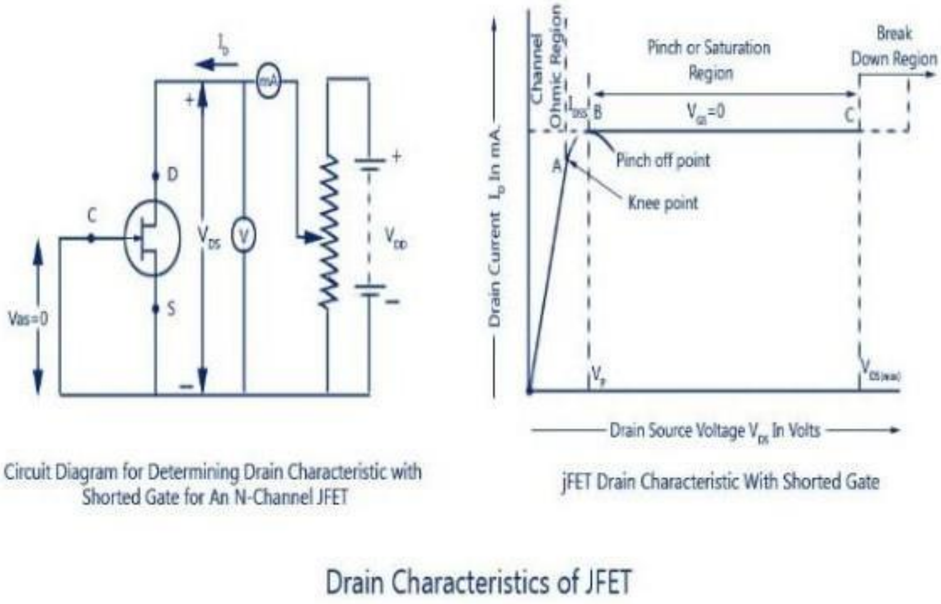


Fig. 4.26 Drain Characteristics of JFET

OUTPUT OR DRAIN CHARACTERISTICS.

- **The curve drawn between drain current Ip and drain-source voltage VDS with gate-to source voltage VGS as the parameter is called the drain or output characteristic. This characteristic is analogous to collector characteristic of a BJT:**

TRANSFER CHARACTERISTICS OF JFET

- **The transfer characteristic for a JFET can be determined experimentally, keeping drain-source voltage, VDS constant and determining drain current, ID for various values of gate-source voltage, VGS.**
- **The circuit diagram is shown in fig. The curve is plotted between gate-source voltage, VGS and drain current, ID , as illustrated in fig. It is similar to the transconductance characteristics of a vaccum tube or a transistor.**
- **It is observed that**
  1. **Drain current decreases with the increase in negative gate-source bias**
  2. **Drain current, ID = IDSS when VGS = 0**
  3. **Drain current, ID = 0 when VGS = VD**

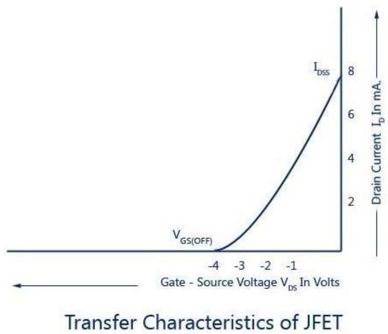


Fig. 4.27 Transfer Characteristics of JFET

The pinch off voltage is the value of VDS at which the drain current reaches its constant saturation value. Any further increase in VDS does not have any effect on the value of ID.

METAL OXIDE SEMICONDUCTOR FIELD EFFECT TRANSISTOR (MOSFET)

MOSFET stands for metal oxide semiconductor field effect transistor which is widely used for switching and amplifying electronic signals in the electronic devices. It is capable of voltage gain and signal power gain. The MOSFET is a core of integrated circuit and it can be designed and fabricated in a single chip because of these very small sizes.

The MOSFET is a four terminal device with source(S), gate (G), drain (D) and body (B) or substrate terminals. The body of the MOSFET is frequently connected to the source terminal so making it a three terminal device like field effect transistor. The MOSFET is very far the most common transistor and can be used in both analog and digital circuits.

The drain and source terminals are connected to the heavily doped regions. The gate terminal is connected top on the oxide layer.The metal of the gate terminal and the semiconductor acts the parallel and the oxide layer acts as insulator of the state MOS capacitor. Between the drain and source terminal inversion layer is formed and due to the flow of carriers in it, the current flows in MOSFET the inversion layer is properties are controlled by gate voltage. Thus it is a voltage controlled device.

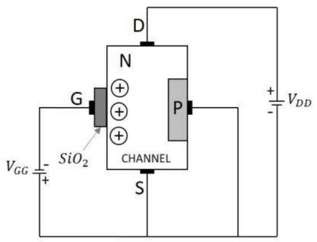


Fig. 4.28 MOSFET

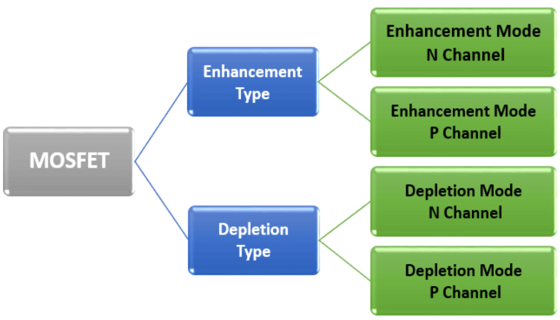


Fig. 4.29 Types of MOSFET

TYPES OF MOSFET

The MOSFET is classified into two types such as;

- Depletion type MOSFET
  - Depletion mode – Negative Gate - Source Voltage (VGS) is applied
  - Enhancement mode – Positive Gate - Source Voltage (VGS) is applied.
- Enhancement type MOSFET

Depletion Type MOSFET:

When there is zero voltage on the gate terminal, the channel shows its maximum conductance. As the voltage on the gate is negative or positive, then decreases the channel conductivity.

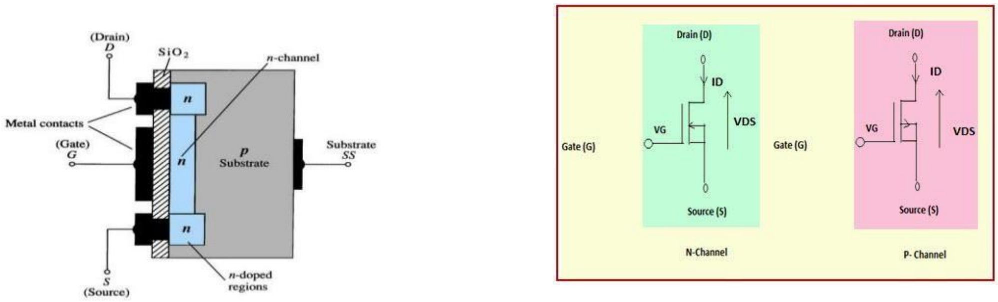
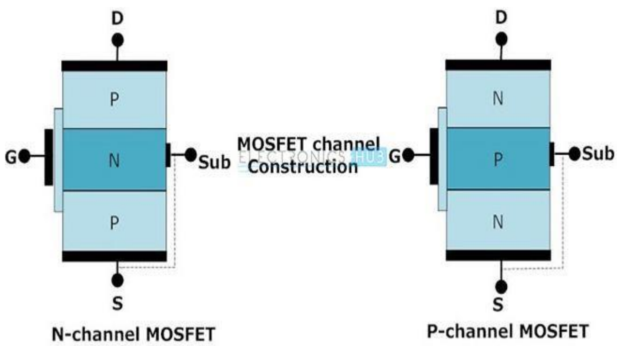


Fig. 4.30 Construction of Depletion Type MOSFET & Symbols

- **The Drain (D) and source (S) leads connect to the n – doped regions**
- **The n doped regions are connected by an N – Channel**
- **This N-Channel is connected to the Gate (G) through a thin insulating layer of SiO2.**
- **The n-doped material lies on a p-doped substrate that may have an additional terminal connection called SS.**

Enhancement type MOSFET:

When there is no voltage on the gate terminal the device does not conduct. More voltage applied on the gate terminal, the device has good conductivity.



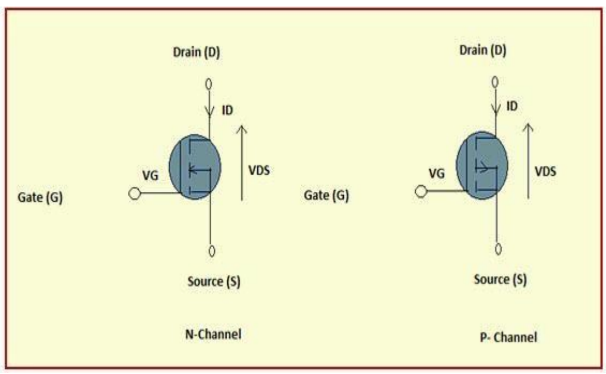


Fig. 4.31Construction of Enhancement Type of MOSFET & Symbols

- **The Enhancement type MOSFET is equivalent to "Normally Open" switch and these types of transistors require gate-source voltage to switch ON the device.**
- **The broken line is connected between the source and drain which represents the enhancement type. In enhancement type MOSFETs the conductivity increases by increasing the oxide layer which adds the carriers to the channel.**
- **Generally, this oxide layer is called as „Inversion layer". The channel is formed between the drain and source in theopposite type to the substrate, such as N-channel is made with a P-type substrate and P-channel is made with an N-type substrate. The conductivity of the channel due to electrons or holes depends on N-type or P-type channel respectively.**

WORKING OF DEPLETION TYPE MOSFET:

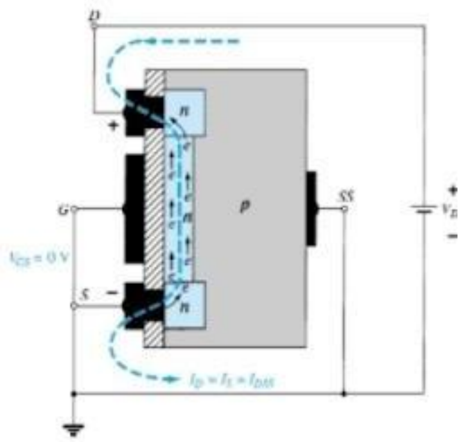


Fig. 4.32 Construction of Enhancement Type of MOSFET & Symbols

Working of Depletion Type MOSFET

The gate-to-source voltage is set to zero volts by the direct connection from one terminal to the other and a voltage VDS is applied across the drain to source terminals. The result is an attraction for the positive potential at the drain by the free electrons of the n-channel and a current similar to that established through the channel of the JFET. In fact, the resulting current with VGS = 0 V continues to be labeled IDSS, as shown in the characteristics of depletion type MOSFET in the below figure.

VGS has been set at a negative voltage such as 1 V. The negative potential at the gate will tend to pressure electrons toward the p-type substrate (like charges repel) and attract holes from the p-type substrate (opposite charges attract) as shown in the above figure

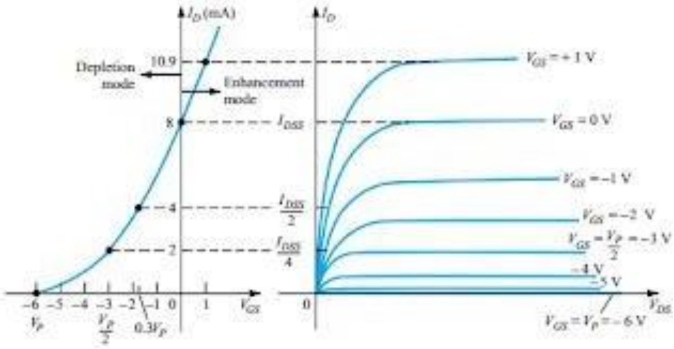


Fig. 4.33 Drain and Transfer Characteristics of Depletion type MOSFET

Depending on the magnitude of the negative bias established by VGS, 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, the higher the rate of recombination. The resulting level of drain current is therefore reduced with increasing negative bias for VGS as shown in the figure below for VGS = - 1 V, - 2 V, and so on, to the pinch-off level of 6 V. The resulting levels of drain current and the plotting of the transfer curve proceeds exactly as described for the JFET.

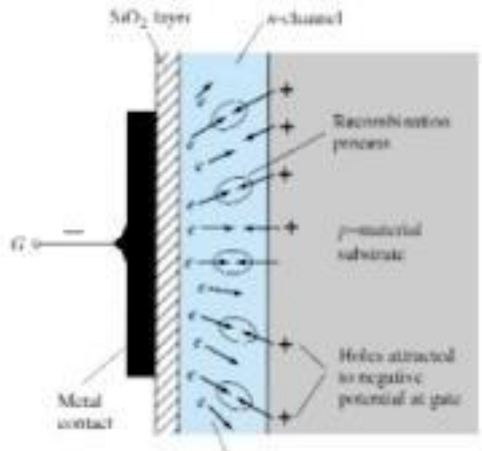


Fig. 4.34 Depletion type MOSFET

For positive values of VGS, the positive gate will draw additional electrons (free carriers) from the p-type substrate due to the reverse leakage current and establish new carriers through the collisions resulting between accelerating particles. As the gate to source voltage continues to increase in the positive direction, characteristics of depletion type MOSFET reveals that the drain current will increase at a rapid rate for the reasons listed above.

The vertical spacing between the VGS = 0 V and VGS = 1 V curves in the characteristic curve is a clear indication of how much the current has increased for the 1-V change in VGS. Due to the rapid rise, the user must be aware of the maximum drain

current rating since it could be exceeded with a positive gate voltage. That is, for the device of figure showing characteristics of depletion type MOSFET, the application of a voltage VGS = 4 V would result in a drain current of

mA, which could possibly exceed the maximum rating (current or power) for the device.

As revealed above, the application of a positive gate-to-source voltage has "enhanced" the level of free carriers in the channel compared to that encountered with VGS = 0 V. For this reason the region of positive gate voltages on the drain or transfer characteristics is often referred to as the enhancement region, with the region between cutoff and the saturation level of IDSS referred to as the depletion region.

WORKING OF ENHANCEMENT TYPE MOSFET(EMOSFET):

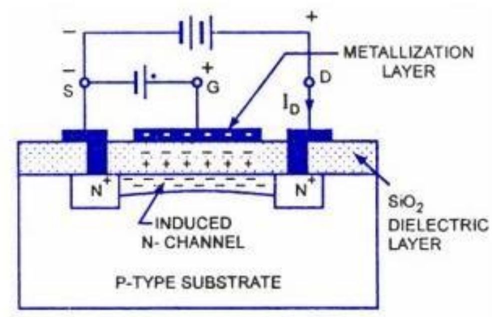


Fig. 4.35 Operation of Enhancement type MOSFET

Working of an EMOSFET

As its name indicates, this MOSFET operates only in the *enhancement mode* and has no depletion mode. It operates with large positive gate voltage only. It does not conduct when the gate-source voltage VGS = 0. This is the reason that it is called normally-off MOSFET. In these MOSFETâ€™s drain current ID flows only when VGS exceeds VGST [gate-to-source threshold voltage].

When drain is applied with positive voltage with respect to source and no potential is applied to the gate two N-regions and one P-substrate from two P-N junctions connected back to back with a resistance of the P-substrate. So a very small drain current that is, reverse leakage current flows. If the P-type substrate is now connected to the source terminal, there is zero voltage across the source substrate junction, and the‾drain-substrate junction remains reverse biased.

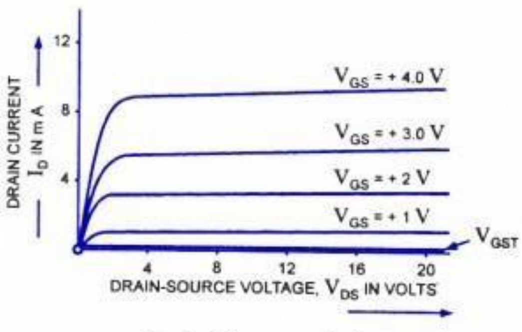
When the gate is made positive with respect to the source and the substrate, negative (i.e. minority) charge carriers within the substrate are attracted to the positive gate and accumulate close to the-surface of the substrate. As the gate voltage is increased, more and more electrons accumulate under the gate. Since these electrons can not flow across the insulated layer of silicon dioxide to the gate, so they accumulate at the surface of the substrate just below the gate. These accumulated minority charge carriers N -type channel

stretching from drain to source. When this occurs, a channel is induced by forming what is termed an *inversion layer* (N-type). Now a drain current start flowing. The strength of the drain current depends upon the channel resistance which, in turn, depends upon the number of charge carriers attracted to the positive gate. Thus drain current is controlled by the gate potential.

Since the conductivity of the channel is enhanced by the positive bias on the gate so this device is also called the *enhancement MOSFET* or E- MOSFET.

The minimum value of gate-to-source voltage VGS that is required to form the inversion layer (N-type) is termed the *gate-to- source threshold voltage* VGST. For VGS below VGST, the drain current ID = 0. But for VGS exceeding VGST an N-type inversion layer connects the source to drain and the drain current ID is large. Depending upon the device being used, VGSTmay vary from less than 1 V to more than 5 V.
JFETs and DE-MOSFETs are classified as the depletion-mode devices because their conductivity depends on the action of depletion layers. E-MOSFET is classified as an enhancement-mode device because its conductivity depends on the action of the inversion layer. Depletion-mode devices are normally ON when the gate-source voltage VGS = 0, whereas the enhancement-mode devices are normally OFF when VGS = 0.

CHARACTERISTICS OF AN EMOSFET.



Drain Characteristics

Fig. 4.36 Characteristics of Enhancement type MOSFET

Drain Characteristics-EMOSFET

Drain characteristics of an N-channel E-MOSFET are shown in the above figure. The lowest curve is the VGST curve. When VGS is lesser than VGST, ID is approximately zero. When VGS is greater than VGST, the device turns- on and the drain current ID is controlled by the gate voltage. The characteristic curves have almost vertical and almost horizontal parts. The almost vertical components of the curves correspond to the ohmic region, and the horizontal components correspond to the constant current region. Thus E-MOSFET can be operated in either of these regions i.e. it can be used as a variable-voltage resistor (WR) or as a constant current source.

EMOSFET-Transfer Characteristics

The above figure shows a typical transconductance curve. The current I_{DSS} at $V_{GS} <=0$ is very small, being of the order of a few nano-amperes. When the V_{GS} is made positive, the drain current I_D increases slowly at first, and then much more rapidly with an increase in V_{GS}. The equation for the transfer characteristic does not obey equation. However it does follow a similar "square law type" of relationship. The equation for the transfer characteristic of E-MOSFETs is given as: $I_D=K(V_{GS}-V_{GST})^2$

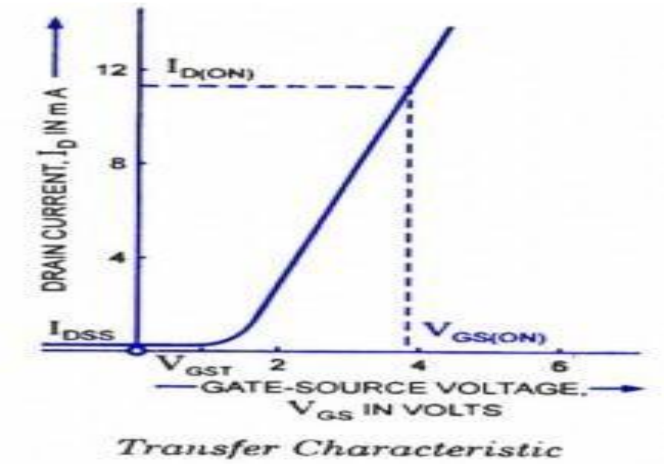


Fig. 4.37 Transfer Characteristics of Enhancement type MOSFET

Handling Precautions for MOSFET

The MOSFET has the drawback of being very susceptible to overload voltage and may require special handling during installation. The MOSFET gets damaged easily if it is not properly handled. A very thin layer of SiO_2, between the gate and channel is damaged due to high voltage and even by static electricity. The static electricity may result from the sliding of a device in a plastic bag. If a person picks up the transistor by its case and brushes the gate against some grounded objects, a large electrostatic discharge may result. In a relatively dry atmosphere, a static potential of 300V is not uncommon on a person who has high resistance soles on his footwear.

MOSFETs are protected by a shorting ring that is wrapped around all four terminals during shipping and must remain in place until after the devices soldered in position. prior to soldering ,the technician should use a shorting strap to discharge his static electricity and make sure that the tip of the soldering iron is grounded. Once in circuit, there are usually low resistances present to prevent any excessive accumulation of electro static charge .However, the MOSFET should never be inserted into or removed from a circuit with the power ON.JFET is not subject to these restrictions, and even some MOSFETs have a built in gate protection known as "integral gate protection", a system built into the device to get around the problem of high voltage on the gate causing a puncturing of the oxide layer. The manner in which this is done is shown in the cross sectional view of Fig.7.11.The symbol clearly shows that between each and the source is placed a back-to-back (or front-to-front) pair of diodes, which are built right into P type substrate.

FET as Voltage-Variable Resistor

FET is operated in the constant-current portion of its output characteristics for the linear applications. In the region before pinch-off, where VDS is small, the drain to source resistance rd can be controlled by the bias voltage VGS. The FET is useful as a voltage variable resistor (VVR) or voltage dependent resistor (VDR).

In JFET, the drain to source conductance gd =ID/VDS for small values of VDS, which may also be expressed as gd=g do [1-(VGS/VP)$^{1/2}$]

Where, gdo is the value of drain conductance when the bias voltage VGS is zero. The variation of the rd with VGS can be closely approximated by the empirical expression,

rd =ro/(1-KVGS)

Where ro=drain resistance at zero gate bias, and K=a constant, dependent upon FET type.

Comparison of MOSFET and JFET

1. **In enhancement and depletion types of MOSFET, the transverse electric field induced across an insulating layer deposited on the semiconductor material controls the conductivity of the channel. In the JFET the transverse electric field across the reverse biased PN junction controls the conductivity of the channel.**
2. **The gate leakage current in a MOSFET is of the order of 10^{-12}A.Hence the input resistance of a MOSFET is very high in the order of 10^{10} to 10^{15} ohm. The gate leakage current of a JFET is of the order of 10^{-9}A and its input resistance is of the order of 10^{8} ohm.**
3. **The output characteristics of the JFET are flatter than those of the MOSFET and hence, the drain resistance of a JFET(0.1 to 1Mohm) is much higher than that of a MOSFET(1 to 50 K ohm)**
4. **JFETs are operated only in the depletion mode. The depletion type MOSFET may be operated in both depletion and enhancement mode.**
5. **Comparing to JFET, MOSFETs are easier to fabricate.**
6. **MOSFET is very susceptible to overload voltage and needs special handling during installation. It gets damaged easily if it is not properly handled.**
7. **MOSFET has zero offset voltage. As it is a symmetrical device, the source and drain can be interchanged. These two properties are very useful in analog signal switching.**
8. **Special digital CMOS circuits are available which involves near –zero power dissipation and very low voltage and current requirements. This makes them most suitable for portable systems.**

Comparison of JFET and BJT

1. **FET operations depend only on the flow of majority carrier-holes for P-channel FETs and electrons for N-channel FETs. Therefore, they are called Unipolar devices. Bipolar transistor (BJT) operation depends on both minority and majority current carrier.**
2. **As FET has no junctions and the conduction is through an N-type or P-type semiconductor material, FET is less noisy than BJT.**

3. As the input circuit of FET is reverse biased, FET exhibits as much higher input impedance (in the order of 100MOHM) and lower output impedance and there will be a high degree of isolation between input and output. So, FET can act as excellent buffer amplifier but the BJT has low input impedance because its input circuit is forward biased.
4. FET is a voltage control device, i.e. voltage at the input terminal controls the output current, whereas BJT is a current control device, i.e. the input current controls the output current.
5. FETs are much easier to fabricate and are particularly suitable for ICs because they occupy less space than BJTs.
6. The performance of BJT is degraded by neutron radiations because of reduction in minority carrier life time, whereas FET can tolerate a much higher level of radiation since they do not rely on minority carrier for their operation.
7. The performance of FET is relatively unaffected by ambient temperature changes. As it has a negative temperature coefficient at high current levels, it prevents the FET from thermal break down. The BJT has a positive temperature coefficient at high current levels which leads to thermal break down.
8. Since FET does not suffer from minority carrier storage effects, it has a higher switching speeds and cut off frequencies.BJT suffers a minority carrier storage effects and therefore has lower switching speed and cut off frequencies.
9. FET amplifiers have low gain bandwidth product due to the junction capacitive effects and produce more signal distortion except for small signal operation.
10. BJT are cheaper to produce than FETs.

Silicon Controlled Rectifier (SCR)

A silicon controlled rectifier is a semiconductor device that acts as a true electronic switch. It can change alternating current into direct current and at the same time can control the amount of power fed to the load. Thus *SCR* combines the features of a rectifier and a transistor.

Constructional details.

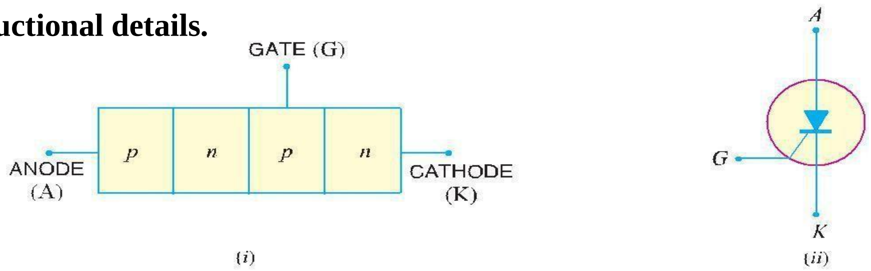


Fig. 4.38 SCR

When a PN junction is added to a junction transistor, the resulting three pn junction device is called a silicon controlled rectifier. Fig. I shows its construction. It is clear that it is essentially an ordinary rectifier (pn) and a junction transistor (npn) combined in one unit to form pnpn device. Three terminals are taken; one from the outer p-type material called anode A, second from the outer n-type material called cathode K and the third from the base of transistor section and is called gate
G. In the normal operating conditions of SCR, anode is held at high positive potential with respect to cathode and gate at small positive potential with respect to cathode. Fig. (ii)

shows the symbol of SCR. The silicon controlled rectifier is a solid state equivalent of thyratron. The gate, anode and cathode of SCR correspond to the grid, plate and cathode of thyratron. For this reason, SCR is sometimes called thyristor.

Working of SCR

In a silicon controlled rectifier, load is connected in series with anode. The anode is always kept at positive potential *w.r.t.*
cathode. The working of *SCR* can be studied under the following two heads:
When gate is open. The below diagram shows that the SCR circuit with gate open i.e. no voltage applied to the gate. Under this condition, junction J2 is reverse biased while junctions J1 and J3 are forward biased. Hence, the situation in the junctions J1 and J3 is just as in a npn transistor with base open. Consequently, no current flows through the load RL and the SCR. However, if the applied voltage is gradually increased, a stage is reached when reverse biased junction J2 breaks down. The SCR now conducts heavily and is said to be in the ON state. The applied voltage at which SCR conducts heavily without gate voltage is called Break over voltage.

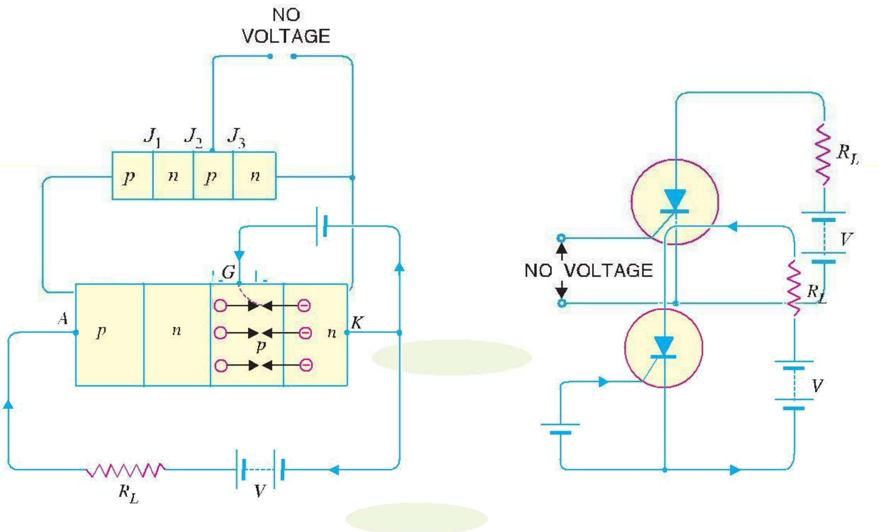


Fig. 4.39 Operation of SCR

(*ii*) When gate is positive w.r.t. cathode.

The SCR can be made to conduct heavily at smaller applied voltage by applying a small positive potential to the gate as shown in Now junction J3 is forward biased and junction J2 is reverse biased. The electrons from n-type material start moving across junction J3 towards left whereas holes from p-type towards the right. Consequently, the electrons from junction J3 are attracted across junction J2 and gate current starts flowing. As soon as the gate current flows, anode current increases. The increased anode current in turn makes more electrons available at junction J2. This process continues and in an extremely small time, junction J2 breaks down and the SCR starts conducting heavily.

Once SCR starts conducting, the gate (the reason for this name is obvious) loses all control. Even if gate voltage is removed, the anode current does not decrease at all. The only way to stop conduction (i.e. bring SCR in off condition) is to reduce the applied voltage to zero.

The whole applied voltage V appears as reverse bias across junction J2 as junctions J1 and J3 are forward biased. Because J1 and J3 are forward biased and J2 has broken down.

Conclusion. The following conclusions are drawn from the working of SCR : An SCR has two states i.e. either it does not conduct or it conducts heavily. There is no state in between. Therefore, SCR behaves like a switch.There are two ways to turn on the SCR. The first method is to keep the gate open and make the supply voltage equal to the breakover voltage. The second method is to operate SCR with supply voltage less than breakover voltage and then turn it on by means of a small voltage (typically 1.5 V, 30 mA) applied to the gate.Applying small positive voltage to the gate is the normal way to close an SCR because the breakover voltage is usually much greater than supply voltage.To open the SCR (i.e. to make it non- conducting), reduce the supply voltage to zero.

VI CHARACTERISTICS OF SCR:

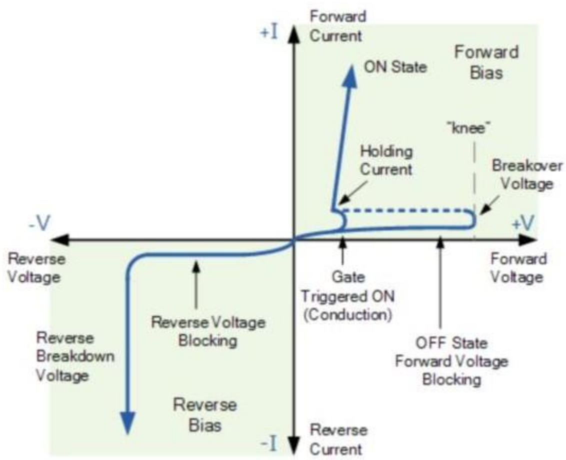


Fig. 4.40 V-I characteristics of SCR

The V-I characteristics of the SCR reveal that the SCR can be operated in three modes. Forward blocking mode (off state) Forward conduction mode (on state) Reverse blocking mode (off state) Forward blocking mode

In this mode of operation, the anode is given a positive potential while the cathode is given a negative voltage, keeping the gate at zero potential i.e. disconnected. In this case junction J1 and J3 are forward biased while J2 is reversed biased due to which only a small leakage current exists from the anode to the cathode until the applied voltage reaches its breakover value, at which J2 undergoes avalanche breakdown and at this breakover voltage it starts conducting, but below breakover voltage it offers very high resistance to the current and is said to be in the off state.

Forward conduction mode

SCR can be brought from blocking mode to conduction mode in two ways: either by increasing the voltage across anode to cathode beyond break over voltage or by applying of positive pulse at gate. Once it starts conducting, no more gate voltage is required to maintain it in the on state. There are two ways to turn it off: 1. Reduce the current through it below a minimum value called the holding current and 2. With the Gate turned off, short out the Anode and Cathode momentarily with a push- button switch or transistor across the junction.

Reverse blocking mode

In this mode SCR is reversed biased , ie when anode is negative compared to cathode. The characteristic of this region are similar to those of an ordinary PN junction diode. in this region ,junctionJ1and J3 are reversed biased whereas j2 is farward biased

.the device behaves as if two diodes are connected in series with a reverse voltage applied to them. A small leakage current of the order of mill amperes or micro amperes flow in the device. This reverse blocking mode is called the OFF state of the thyristor .when the reverse voltage of the SCR increases to a large extent breakdown occurs and the current in the device increases rapidly. Thus when the SCR is biased in this region the power dissipated is very high, if the power dissipated is more than the rated value of the SCR , the SCR is permanently damaged .thus in the reverse bias condition the voltage should never cross the breakdown voltage.

Characteristics of SCR

It is the curve between anode-cathode voltage (V) and anode current (I)of an SCR at constant gate current

Forward characteristics.

When anode is positive w.r.t. cathode, the curve between V and I is called the forward characteristic. In the above fig, OABC is the forward characteristic of SCR at IG = 0.If the supply voltage is increased from zero, a point is reached (point A) when the SCR starts conducting. Under this condition, the voltage across SCR suddenly drops as shown by dotted curve AB and most of supply voltage appears across the load resistance RL. If proper gate current is made to flow,SCR can close at much smaller supply voltage.

Reverse characteristics.

When anode is negative w.r.t. cathode, the curve between V and I is known as reverse characteristic. The reverse voltage does come across SCR when it is operated witha.c. supply. If the reverse voltage is gradually increased, at first the anode current remains small (i.e.leakage current) and at some reverse voltage, avalanche breakdown occurs and the SCR starts conducting heavily in the reverse direction as shown by the curve DE. This maximum reverse voltage at which SCR starts conducting heavily is known as reverse breakdown voltage.

EQUIVALENT CIRCUIT OF SCR

The *SCR* shown in Fig. 20.4 (*i*) can be visualised as separated into two transistors as shown in

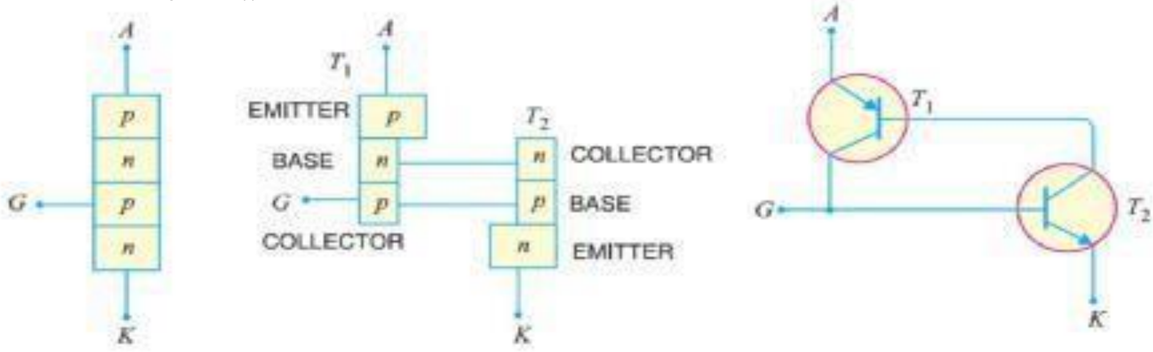


Fig. 4.41 Equivalent circuit of SCR

Thus, the equivalent circuit of *SCR* is composed of *pnp* transistor and *npn* transistor connected as shown in the above fig. It is clear that collector of each transistor is coupled to the base of the other, thereby making a positive feedback loop. The working of *SCR* can be easily explained from its equivalent circuit. The above fig shows the equivalent circuit of *SCR* with supply voltage *V* and load resistance *RL*. Assume the supply voltage *V* is less than break over voltage as is usually the case.
With gate open (*i.e.* switch *S* open), there is no base current in transistor *T*2. Therefore, no current flows in the collector of *T*2 and hence that of *T*1. Under such conditions, the

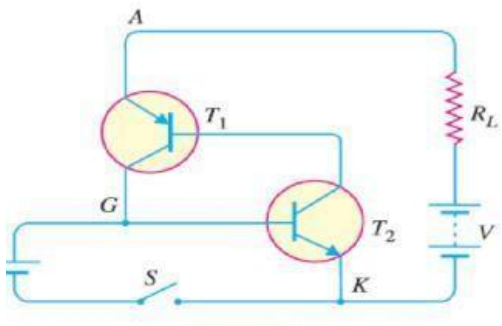


Fig. 4.42 Equivalent circuit of SCR **– Two Transistor model**

***SCR* is open. However, if switch *S* is closed, a small gate current will flow through the base of *T*2 which means its collector current will increase.**

The collector current of *T*2 is the base current of *T*1.Therefore, collector current of *T*1 increases. But collector current of *T*1 is the base current of *T*2. This action is accumulative since an increase of current in one transistor causes an increase of current in the other transistor. As a result of this action, both transistors are driven to saturation, and heavy current flows through the load *RL*. Under such conditions, the *SCR* closes.

APPLICATIONS

SCRs are used in many areas of electronics where they find uses in a variety of different applications. Some of the more common applications for them are outlined below:

- AC power control (including lights, motors,etc).
- Overvoltage protection crowbar for power supplies.
- AC power switching.
- Control elements in phase angle triggered controllers.
- Within photographic flash lights where they act as the switch to discharge a stored voltage through the flash lamp, and then cut it off at the required time.

Thyristors are able to switch high voltages and withstand reverse voltages making them ideal for switching applications, especially within AC scenarios.

UNI JUNCTION TRANSISTOR (UJT)

A unijunction transistor (abbreviated as UJT) is a three-terminal semiconductor switching device. This device has a unique characteristic that when it is triggered, the emitter current increases regeneratively until it is limited by emitter power supply. Due to this characteristic, the unijunction transistor can be employed in a variety of applications e.g., switching, pulse generator, saw-tooth generator etc

CONSTRUCTION.

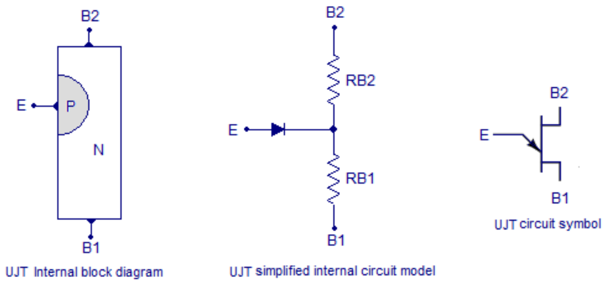


Fig. 4.43 UJT

The above Fig shows the basic structure of a unijunction transistor. It consists of an n-type silicon bar with an electrical connection on each end. The lead to these connections arecalled base leads base-one B1 and base two B2. Part way along the bar between the two bases, nearer to B2 than B1, a pn junction is formed between a p-type emitter and the bar. The lead to this junction is called the emitter lead E. Fig shows the symbol of unijunction transistor. Note that emitter is shown closer to B2 than B1.
i)Since the device has one pn junction and three leads, it is commonly called a unijunction transistor (uni means single).

With only one pn-junction, the device is really a form of diode. Because the two base terminals are taken from one section of the diode, this device is also called double-based diode.

The emitter is heavily doped having many holes. The n region, however, is lightly doped. For this reason, the resistance between the base terminals is very high (5 to 10 kΩ) when emitter lead is open.

WORKING PRINCIPLE OF UJT

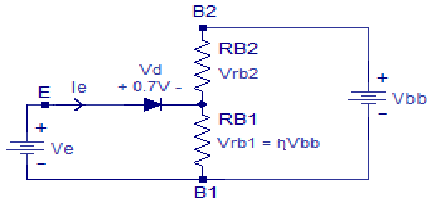


Fig. 4.44 Operation of UJT

The above fig shows the basic circuit operation of a unijunction transistor. The device has normally B2 positive w.r.t. B1.If voltage VBB is applied between B2 and B1 with emitter open, a voltage gradient is established along the n-type bar. Since the emitter is located nearer to B2, more than half of VBB appears between the emitter and B1. The voltage V1 between emitter and B1 establishes a reverse bias on the pn junction and the emitter current is cut off. Of course, a small leakage current flows from B2 to emitter due to minority carriers.
If a positive voltage is applied at the emitter, the pn junction will remain reverse biased so long as the input voltage is less than V1. If the input voltage to the emitter exceeds V1, the pn junction becomes forward biased. Under these conditions, holes are injected from p-type material into the n-type bar. These holes are repelled by positive B2 terminal and they are attracted towards B1 terminal of the bar. This accumulation of holes in the emitter to B1 region results in the decrease of resistance in this section of the bar. The result is that internal voltage drop from emitter to B1 is decreased and hence the emitter current IE increases. As more holes are injected, a condition of saturation will eventually be reached. At this point, the emitter current is limited by emitter power supply only. The device is now in the ON state.
If a negative pulse is applied to the emitter, the pn junction is reverse biased and the emitter current is cut off. The device is then said to be in the OFF state.

Intrinsic standoff ratio:

For ease of understanding, the internal model of the UJT is used in the circuit. B2 terminal of the UJT is made positive with respect to B1 terminal using the voltage source Vbb. Emitter terminal E of the UJT is forward biased using the voltage source Ve. Current starts flowing into the emitter only when the bias voltage Ve has exceeded the forward drop of the internal diode (Vd) plus the voltage drop across RB1 (Vrb1). This condition can be expressed using the following equation.

Ve = Vd + Vrb1

Vrb1 = Vbb* (RB1/(RB1+RB2))

Considering the intrinsic stand off ratio η = RB1/(RB1+RB2), the equation becomes

Ve = Vd+ η ·Vbb

A typical silicon diode has a forward voltage drop of 0.7V. When this factor is considered, the equation can be re written as

Ve = 0.7V + η ·Vbb

CHARACTERISTICS OF UJT

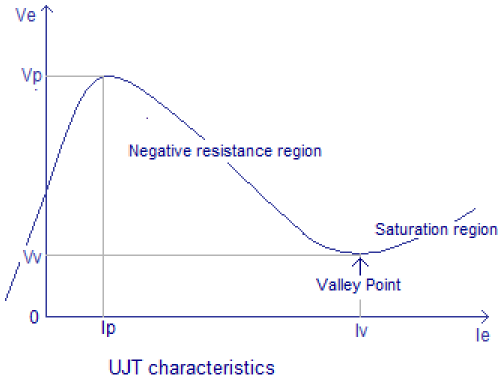


Fig. 4.45 Characteristics of UJT

The above Fig. shows the curve between emitter voltage (VE) and emitter current (IE) of a UJT at a given voltage VBB between the bases. This is known as the emitter characteristic of UJT. The following points may be noted from the characteristics :
(I)Initially, in the cut-off region, as VE increases from zero, slight leakage current flows from terminal B2 to the emitter. This current is due to the minority carriers in the reverse biased diode.
Above a certain value of VE, forward IE begins to flow, increasing until the peak voltage VP and current IP are reached at point P.
After the peak point P, an attempt to increase VE is followed by a sudden increase in emitter current IE with a corresponding decrease in VE. This is a negative resistance portion of the curve because with increase in IE, VE decreases. The device, therefore, has a negative resistance region which is stable enough to be used with a great deal of reliability in many areas e.g., trigger circuits, sawtooth generators, timing circuits.

ADVANTAGES OF UJT

The UJT was introduced in 1948 but did not become commercially available until 1952. Since then, the device has achieved great popularity due to the following reasons :

- **It is a low cost device.**
- **It has excellent characteristics.**
- **It is a low-power absorbing device under normal operating conditions.**

APPLICATIONS OF UJT

Due to above reasons, this device is being used in a variety of applications. A few include oscillators, trigger circuits, saw- tooth generators, bistable network etc.
The UJT is very popular today mainly due to its high switching speed.

A few selected applications of the UJT are as follows:
It is used to trigger SCRs and TRIACs It is used in non-sinusoidal oscillators

It is used in phase control and timing circuits It is used in saw tooth generators
It is used in oscillator circuit design.

TEXT / REFERENCE BOOKS

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