SEEA1103 - ELECTRICAL AND ELECTRONICS ENGINEERING

UNIT- IV - SEMICONDUCTOR DEVICES

- VI 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: It is a material taht 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: It is a material that has its conductivity 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 : 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.
  - Intrinsic semiconductor has very limited applications as they conduct very small amounts of current at room temperature.

- Extrinsic semiconductor

  - The current conduction capability of intrinsic semiconductor can be increased

  significantly by adding a small amounts impurity to the intrinsic semiconductor.

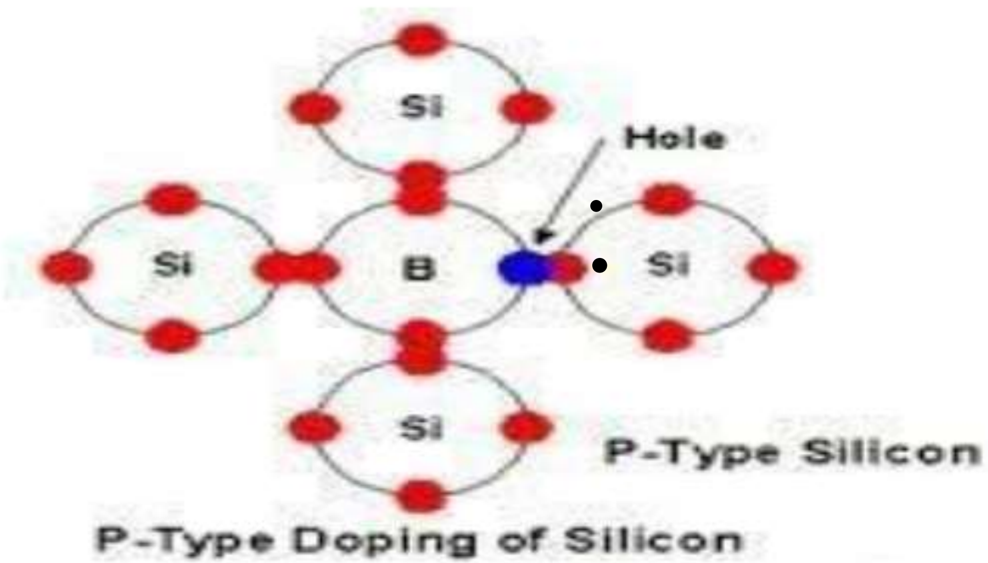
  - By adding impurities it becomes impure or extrinsic semiconductor.
  - This process of adding impurities is called as doping.
  - The amount of impurity added is 1 part in 106 atoms

Properties of extrinsic semiconductors

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

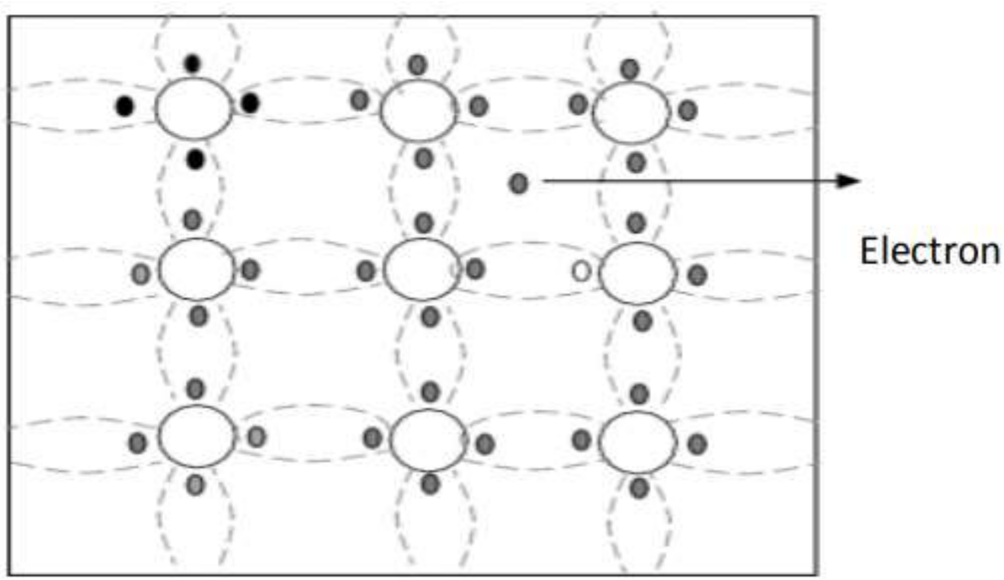


P type Semiconductor

P type semiconductor

- 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



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.
- The crystal structure of N type semiconductor material shown in fig. has four out of five valance electrons of the impurity atom(antimony) forms covalent bond with the four intrinsic semiconductor atoms.

N type semiconductor

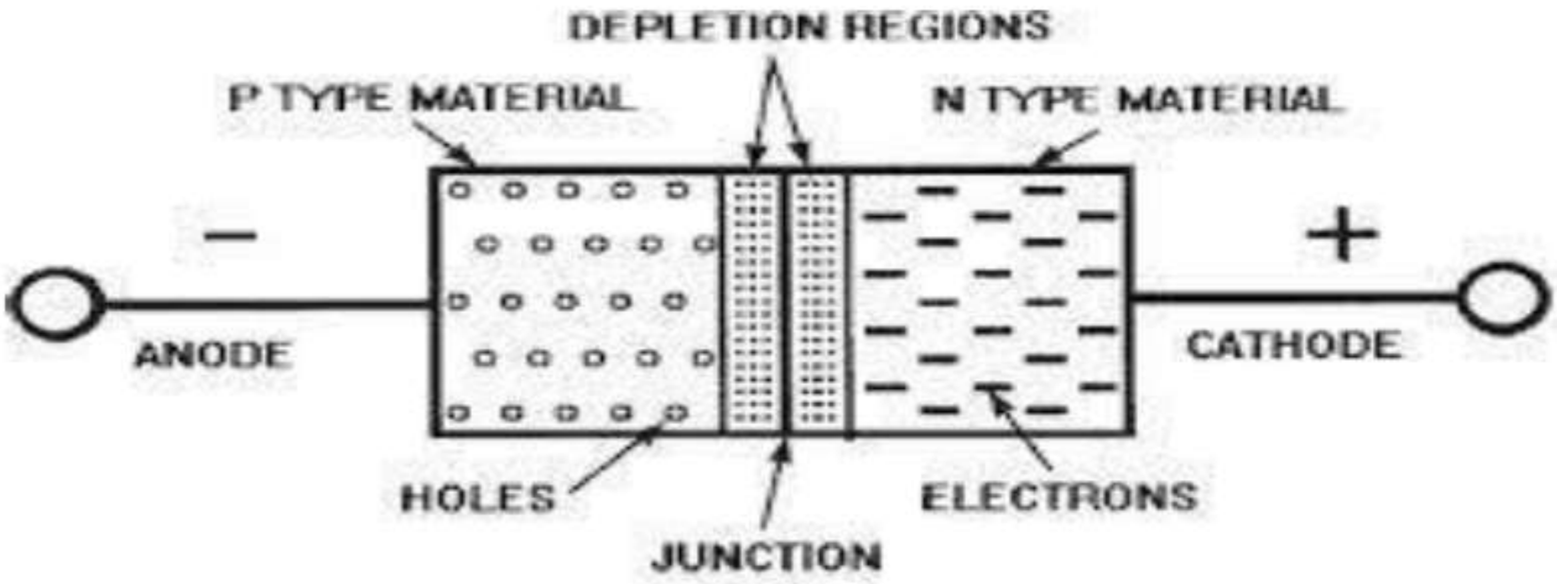
•The fifth electron is loosely bound to the impurity atom.

•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.

PN JUNCTION



- 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 Ptype 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 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.

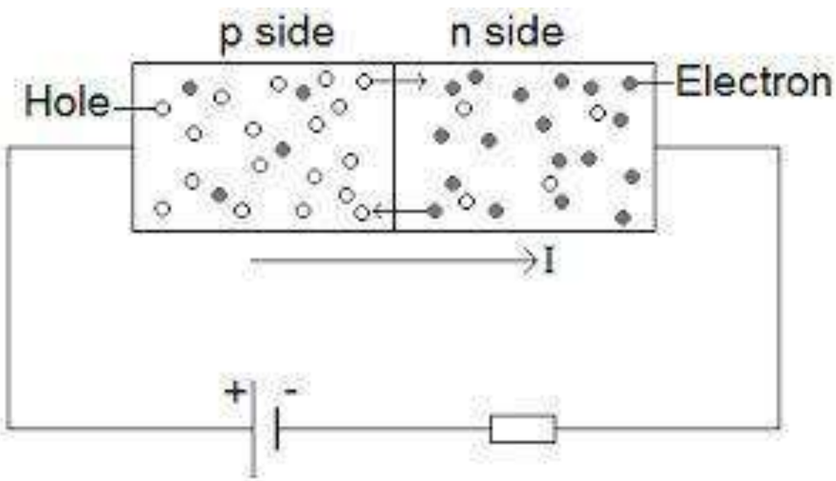
- Thus near the junction, a region depleted of mobile charge carriers is formed.

- 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.

FORWARD BIASED OPERATION



Forward bias PN junction diode

• 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.

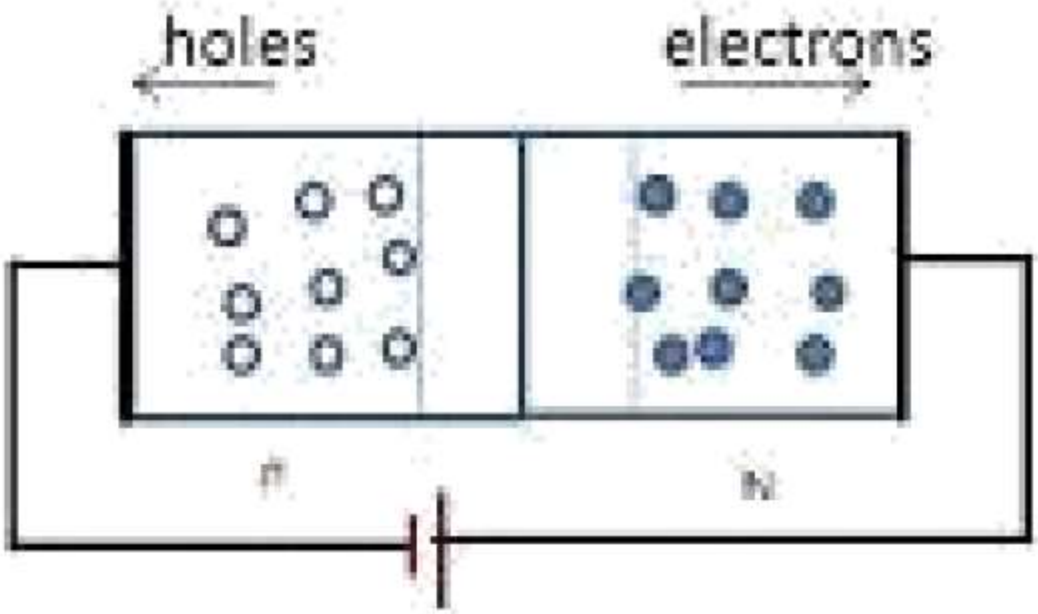
•The majority charge carriers in N and P regions are attracted towards the PN junction and the width of the depletion layer decreases with diffusion of the majority charge carriers.

•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.

Reverse Bias Operation



Reverse bias PN junction diode

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.

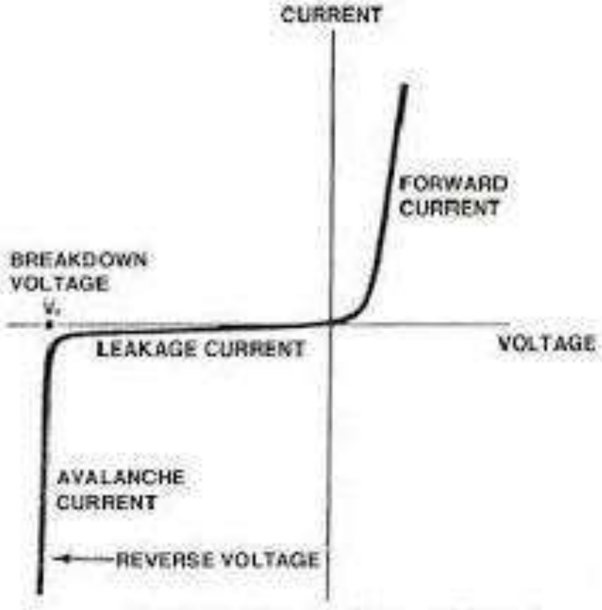
- As a result of it, the width of the potential barrier increases that impedes the flow of majority carriers in N side and P side.

- 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.

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.

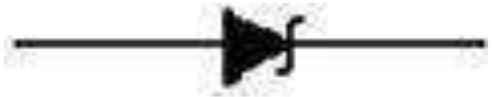
In reverse bias condition, the P-type of the PN junction is connected to the negative terminal and N-type is connected to the positive terminal of the external voltage.

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.

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.

- **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.

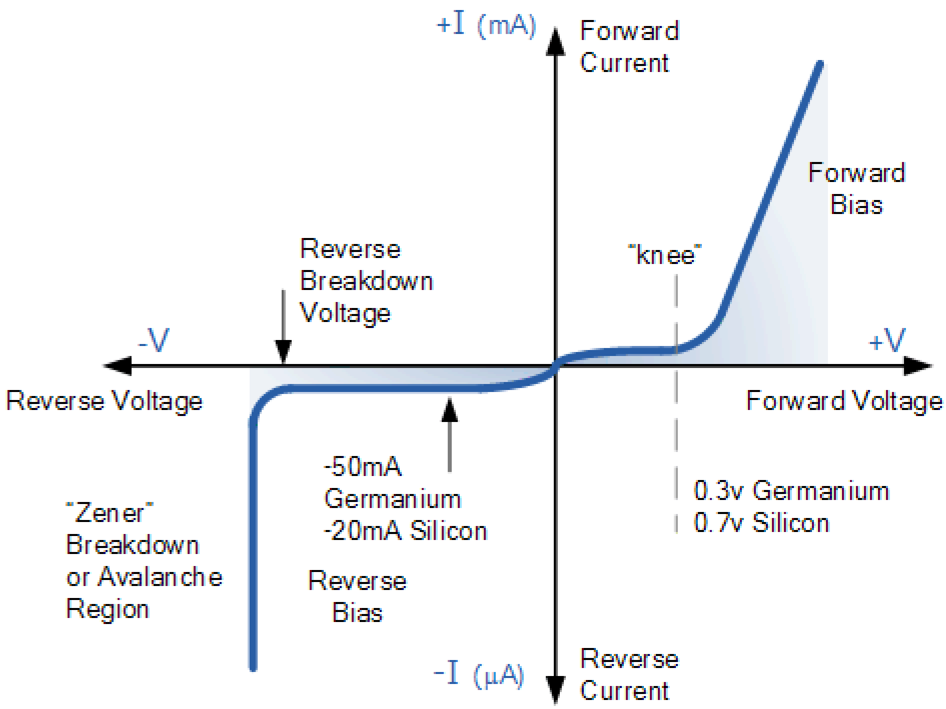
- **Note:**
- Zener breakdown occurs at low reverse voltage whereas avalanche breakdown occurs at high reverse voltage.

- 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.

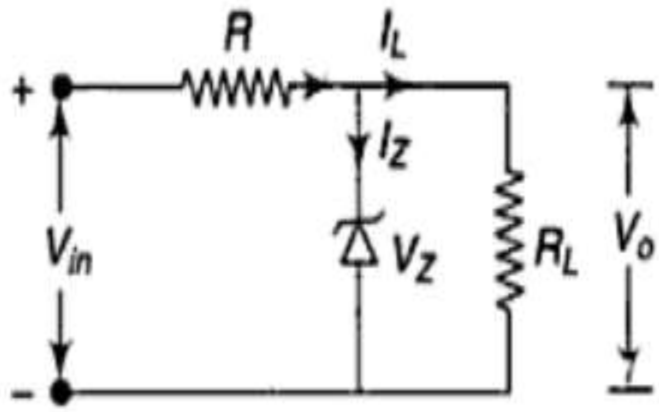
ZENER DIODE CHARACTERISTICS



VI characteristics of Zener diode

- 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.

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.

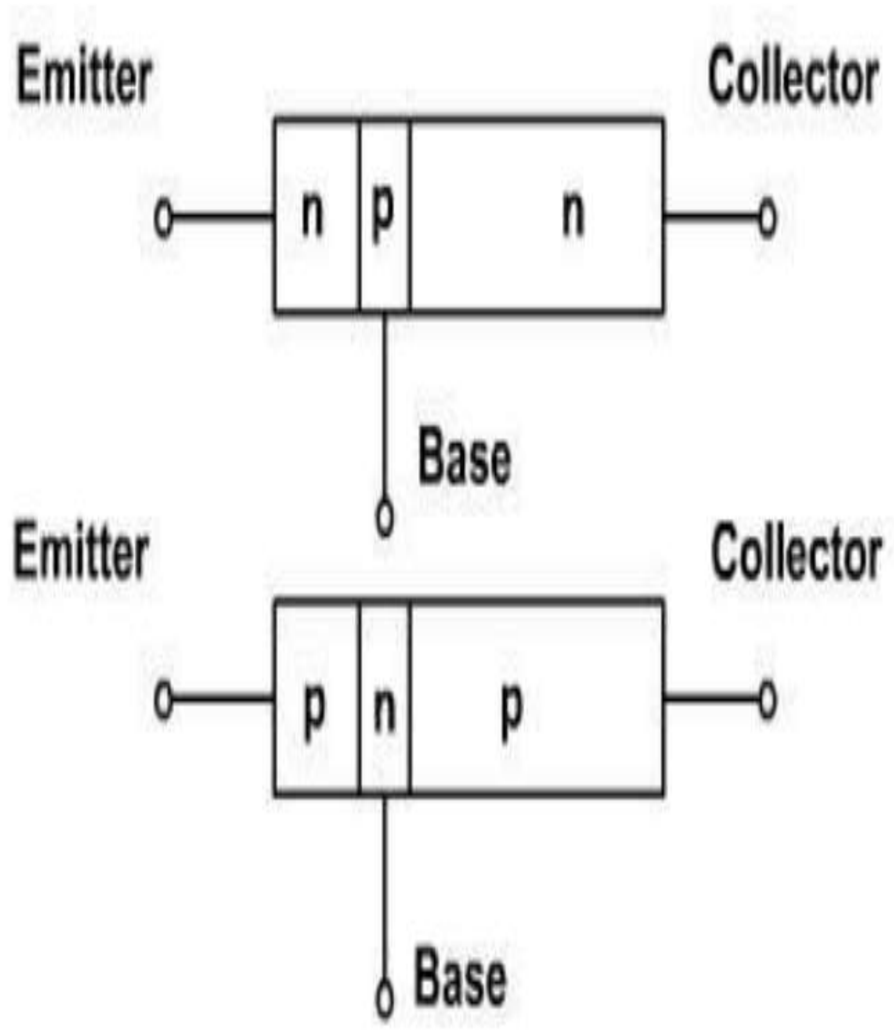
- It is required to provide constant voltage across load resistance RL , whereas the input voltage may be varying over a range.

- 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 ntype semiconductor layers between a pair of opposite types.

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:

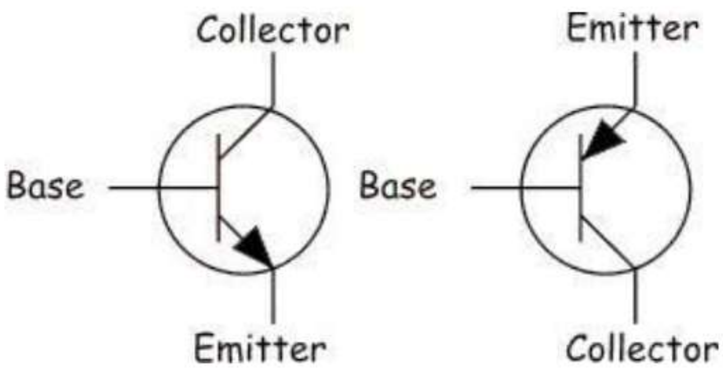
It is the middle region that forms two P-N junction in the transistor.The base of the transistor is thin as compared to the emitter and is a lightly doped region

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**

The transistor symbol carries an arrow head in the emitter pointing from the P- region towards the N- region

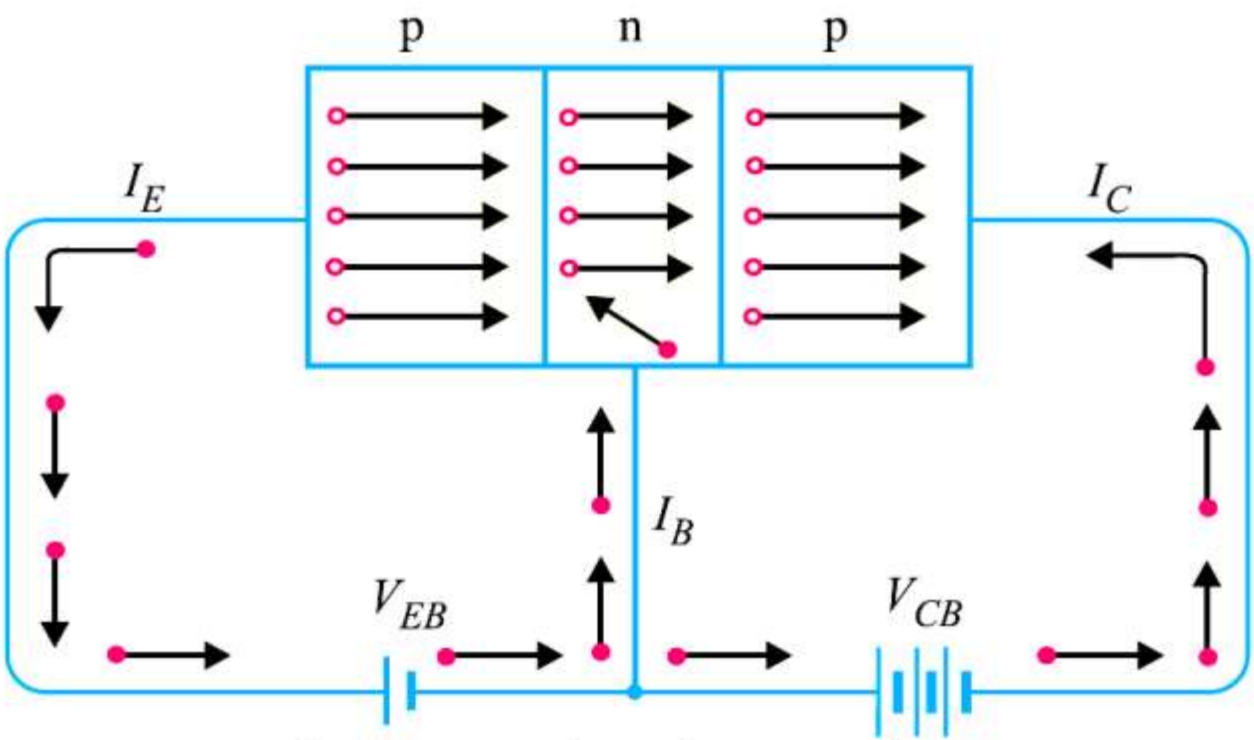
The arrow head indicates the direction of a conventional current flow in a transistor.

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.

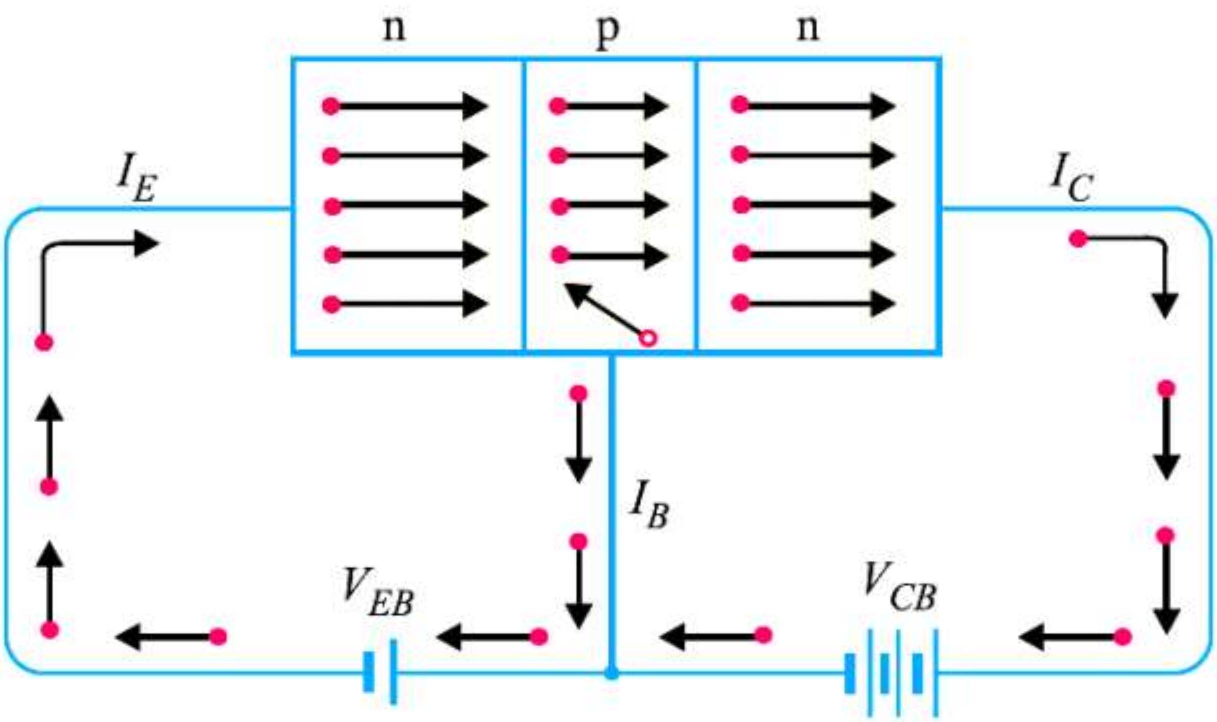
OPERATION OF PNP TRANSISTOR



Basic connection of *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 (I_E).
- The holes after reaching the base region combine with the electrons in the base and constitute base current (I_B).
- 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 (I_C).
- 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.

OPERATION OF NPN TRANSISTOR



Basic connection of *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).

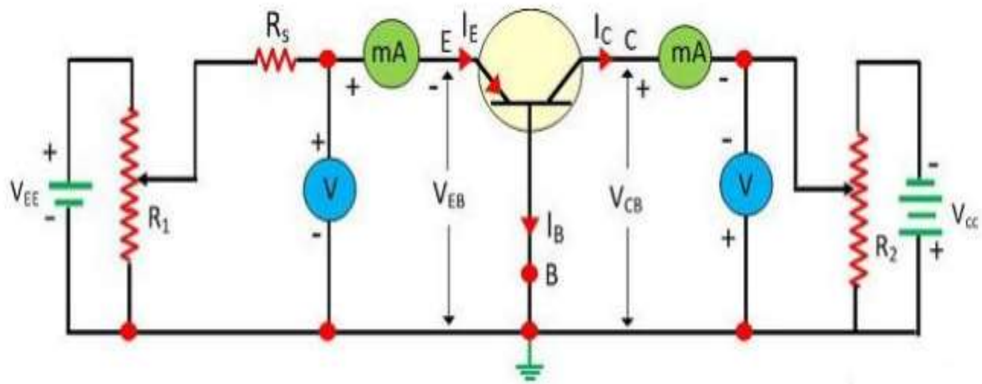
- This collector current is also called injected current, because of this current is produced due to electrons injected from the emitter region

- There is another component of collector current due to the thermal generated carriers.

- This is called as reverse saturation current and is quite small.

- 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)



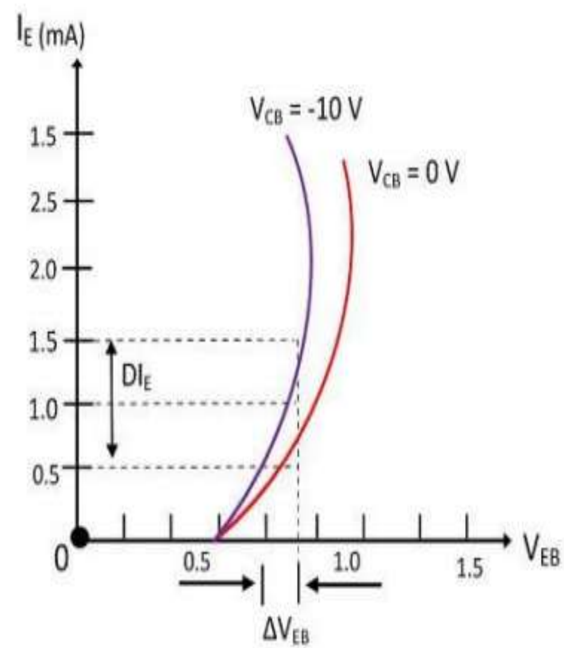
- The input is connected between emitter and base and output is connected across collector and base
- The emitter – base junction is forward biased and collector – base junction is reverse biased.
- The emitter current, flows in the input circuit and the collector current flows in the output circuit.
- 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



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 input resistance. The input resistance is expressed by the $r_i = \frac{\Delta V_{EB}}{\Delta I_E}$ formula

Base width modulation (or) Early effect

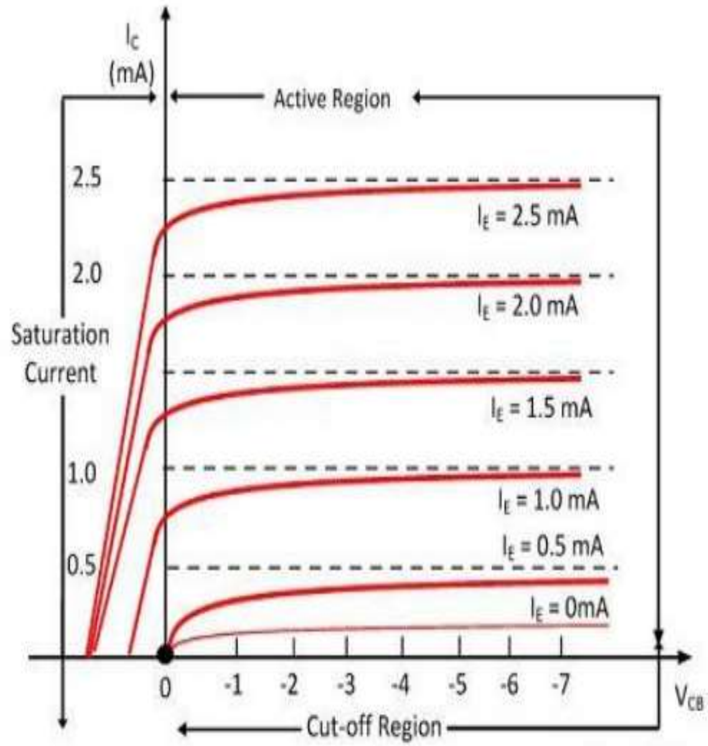
- In a transistor, since the emitter – base junction is forward biased there is no effect on the width of the depletion region.
- However, since collector – base junction is reverse biased, as the reverse bias voltage across the collector – base junction increases the width of the depletion region also 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.



- The active region of the collector-base junction is reverse biased, the collector current I_C is almost equal to the emitter current I_E. The transistor is always operated in this region.
- The curve of the active regions is almost flat. The large charges in V_{CB} produce only a tiny change in I_C. The circuit has very high output resistance r_o.
- When V_{CB} 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., I_{CBO}. 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.

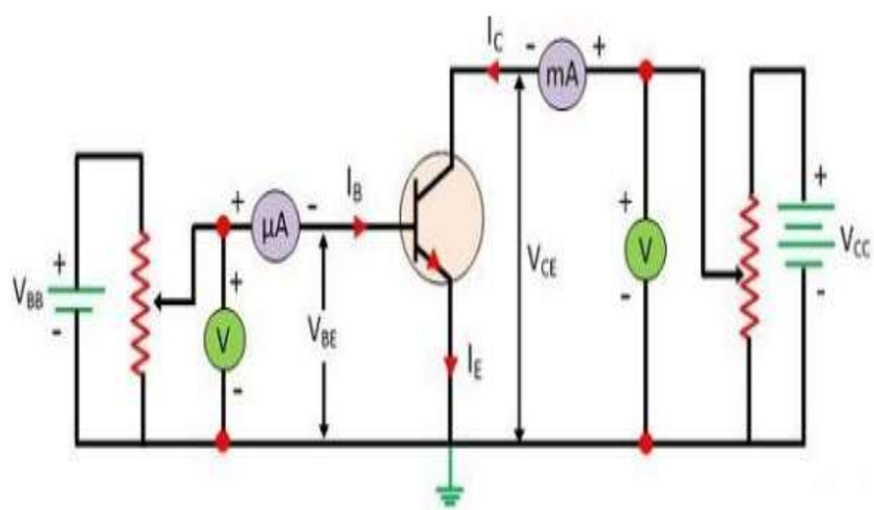
Output Resistance

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

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

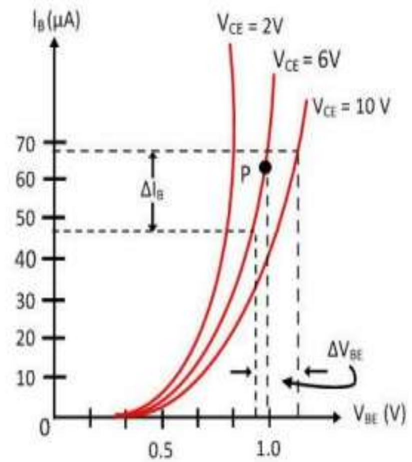
COMMON – EMITTER CONFIGURATION

- 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.



INPUT CHARACTERISTICS

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



- The curve for common Emitter configuration is similar to a forward diode characteristic.
- The base current I_B increases with the increases in the emitter-base voltage V_{BE}. 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 V_{CE} on the input characteristic is ignored.

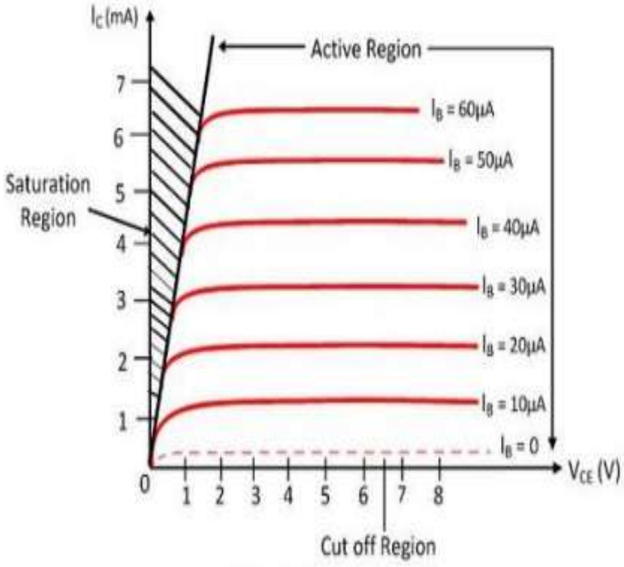
Input Resistance:

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 I_C and collector-emitter voltage V_{CE} at a constant base current I_B is called output characteristic. The characteristic curve for the typical NPN transistor in CE configuration is shown in the figure below.



Output Characteristic Curve

- 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 I_C increases with the increase in V_{CE} at constant voltage I_B, the value β of also increases.
- When the V_{CE} falls, the I_C 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 $I_C = \beta IB$, a small current I_C is not zero, and it is equal to reverse leakage current I_{CEO}.

Output Resistance:

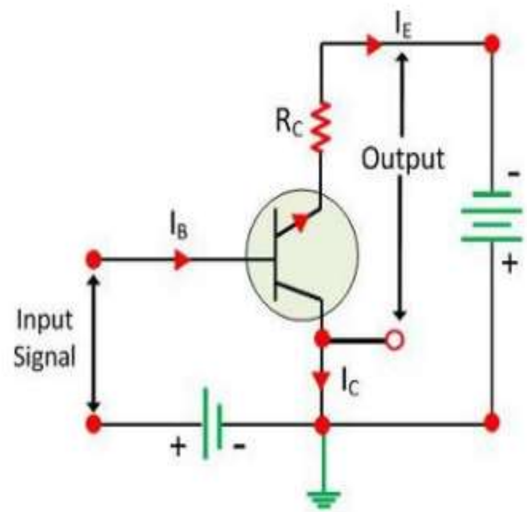
The ratio of the variation in collector-emitter voltage to the collector-emitter current is known at collector currents at a constant base current I_B is called output resistance ro.

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

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

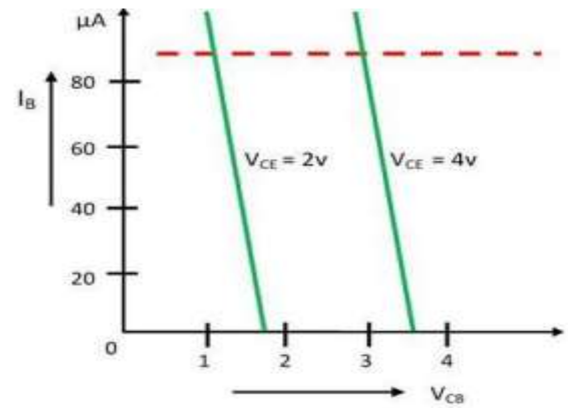
COMMON - COLLECTOR CONFIGURATION

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.



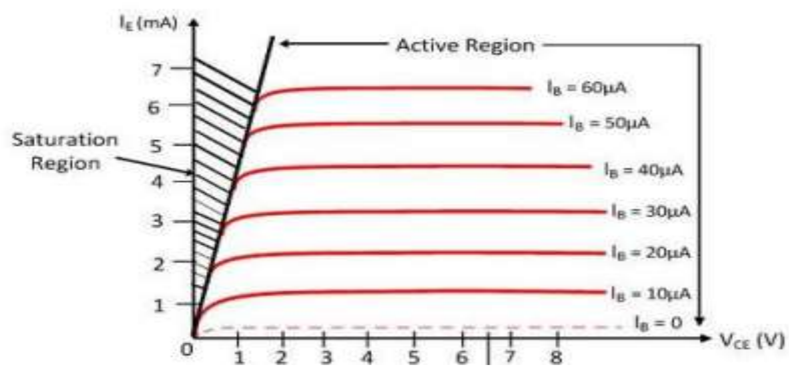
INPUT CHARACTERISTICS

The input characteristic of the common collector configuration is drawn between collector base voltage V_{CE} and base current I_B at constant emitter current voltage V_{CE}. The value of the output voltage V_{CE} changes with respect to the input voltage V_{BC} and I_B With the help of these values, input characteristic curve is drawn. The input characteristic curve is shown below.



OUTPUT CHARACTERISTICS

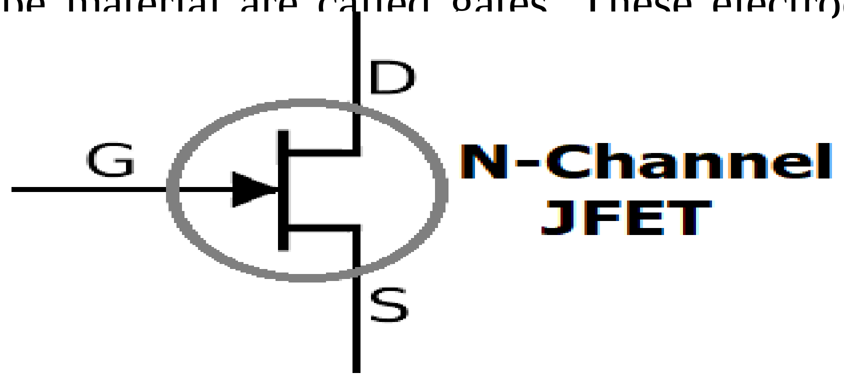
The output characteristic of the common emitter circuit is drawn between the emitter-collector voltage VEC and output current IE at constant input current IB. If the input current IB is zero, then the collector current also becomes zero, and no current flows through the transistor.

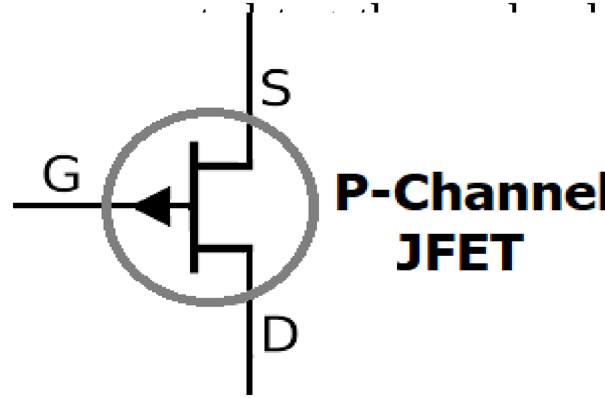


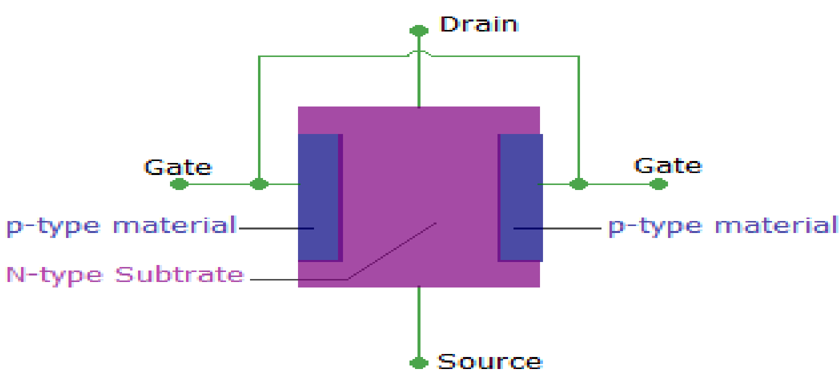
The transistor operates in active region when the base current increases and reaches to saturation region. The graph is plotted by keeping the base current I_B constant and varying the emitter-collector voltage V_{CE}, the values of output current I_E are noticed with respect to V_{CE}. By using the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

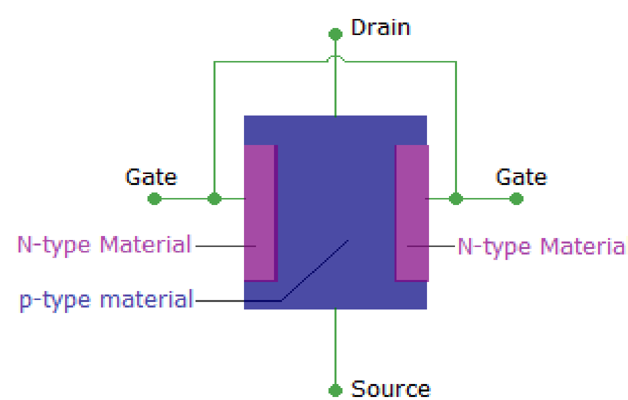
JUNCTION FIELD EFFECT TRANSISTOR (JFET)

- The Junction Field Effect Transistor, or JFET, is a **voltage controlled three terminal unipolar semiconductor device**
- The **Junction Field Effect Transistor** has no PN-junctions but instead has a narrow piece of high resistivity semiconductor material forming a "Channel" of either N-type or P-type silicon for the majority carriers to flow through with two ohmic electrical connections at either end commonly called the Drain and the Source respectively.
- 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 electrod ... one



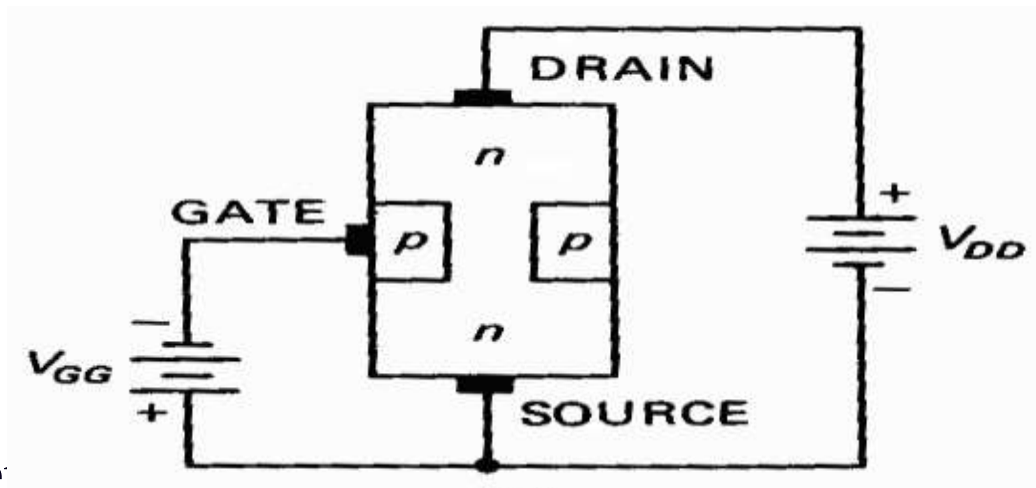






OPERATION OF JFET

- Both N-channel JFET and **p-channel JFET** operated in the same way, although the charge carriers are inverted i.e. **electrons** are majority carriers in n-channel and **holes** are majority carriers in p-channel.
- The width of the channel varies in accordance with the magnitude of the bias voltage applied to the gate terminal and source-drain terminal.



(a)

- Jfe the voltage applied acr
- **(i)** **No voltage:**

When neither any voltage is applied across source to drain terminal i.e. Vds = 0 nor any bias is applied to the gate terminal i.e. Vgs= 0, the depletion region around the p-n junction are of equal thickness and symmetrical in nature.

OPERATION OF JFET(contd..)

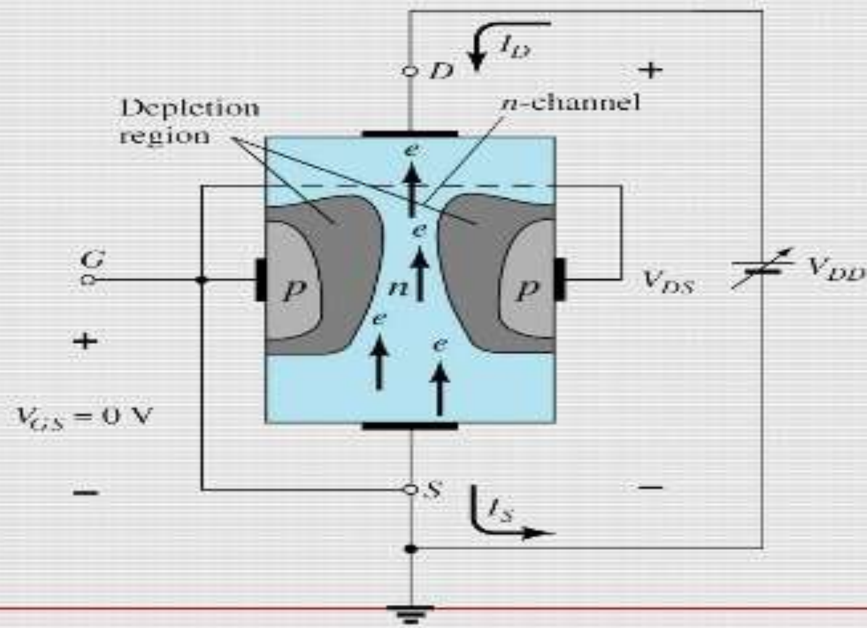
- **(ii) Negative Voltage:**
- When the gate is negative bias with respect to the source and drain is applied with a positive bias with respect to the source, the p-n junction got reverse biased and forms depletion region. When the drain current flows through the channel, there is a voltage drop along its length. The result is that the reverse bias at the drain end is more than that at the source end making the width of depletion layer more at the drain. With the increasing resistance and reducing current I_d , the channel starts narrowing. If we further increase the negative voltage across the gate, depletion layers meet at the centre and the drain current cut off completely. Similarly, if we reduce the negative voltage across the gate, the depletion layers start reducing causing decrease in resistance and increase in drain current I_d.

OPERATION OF JFET(contd..)

- **(iii) Positive voltage:**
- When positive voltage is applied to the drain terminal D w.r.t. source terminal S without connecting gate terminal G to supply, as illustrated in fig. 9.4, the electrons (which are the majority carriers) flow from terminal S to terminal D whereas conventional drain current I_D flows through the channel from D to S. Due to flow of this current, there is uniform voltage drop across the channel resistance as we move from terminal D to terminal S. This voltage drop reverse biases the diode. The gate is more "negative" with respect to those points in the channel which are nearer to D than to S. Hence, depletion layers penetrate more deeply into the channel at points lying closer to D than to S. Thus wedge-shaped depletion regions are formed, as shown in figure. when Vd_s is applied. The size of the depletion layer formed determines the width of the channel and hence the magnitude of current I_D flowing through the channel.

OPERATION OF JFET(contd..)

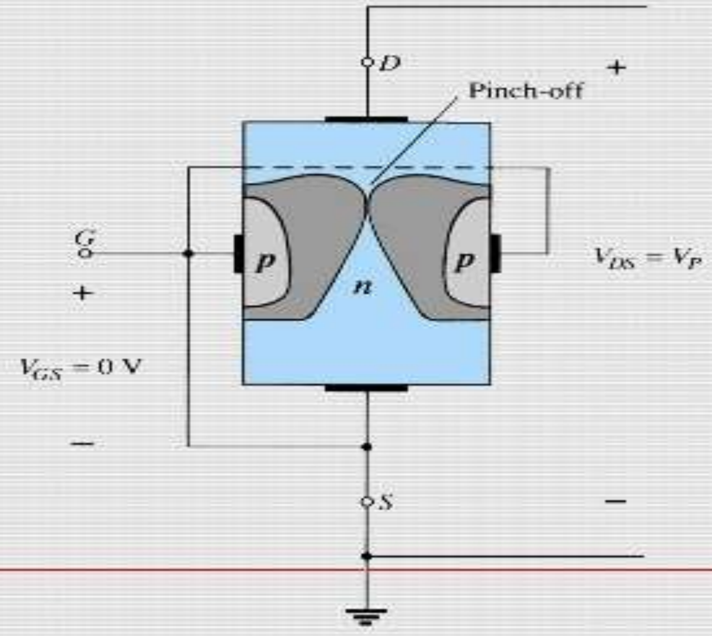
JFET for $V_{GS} = 0$ V and $0 < V_{DS} < |V_p|$



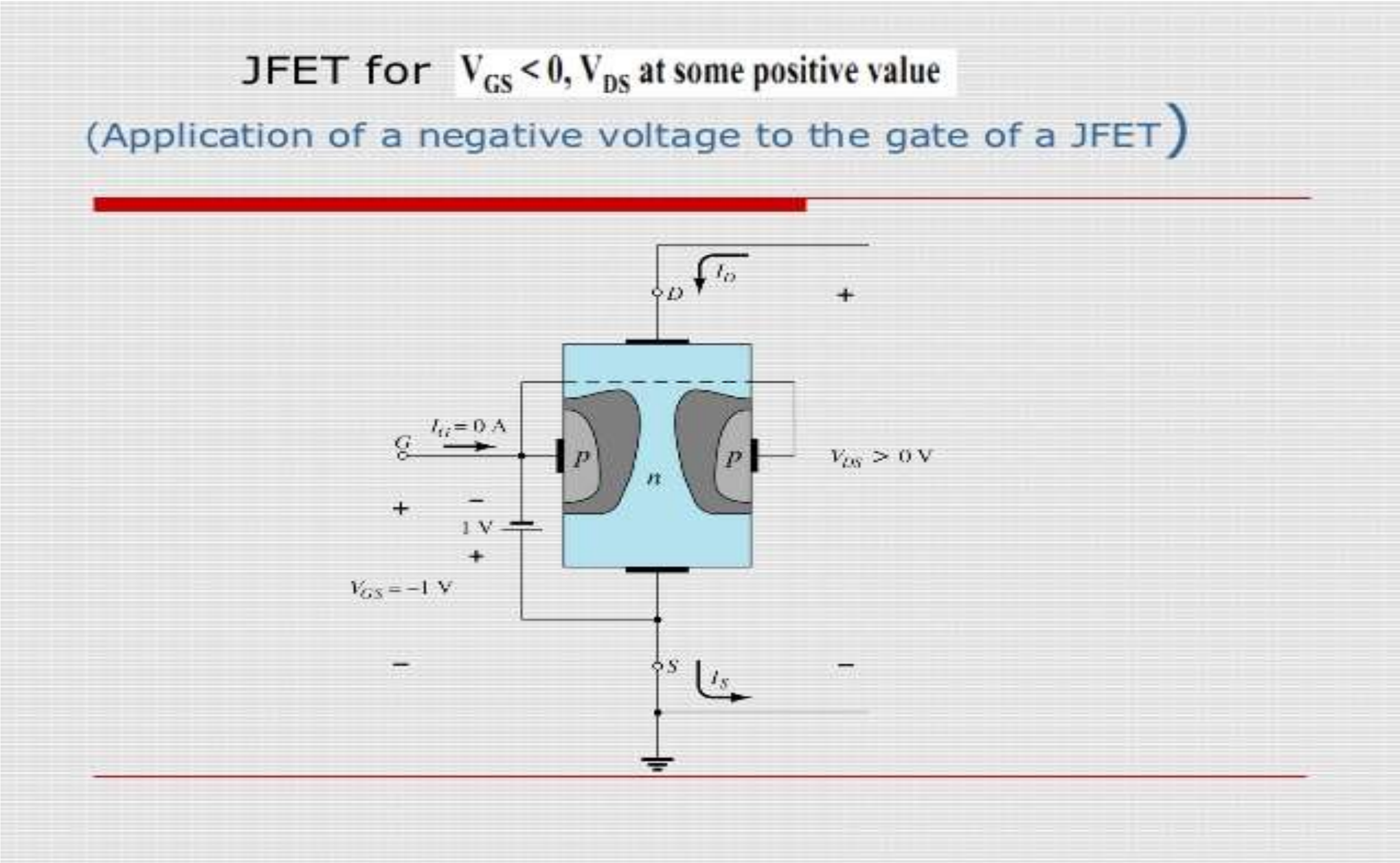
Channel becomes narrower as V_{DS} is increased

OPERATION OF JFET(contd..)

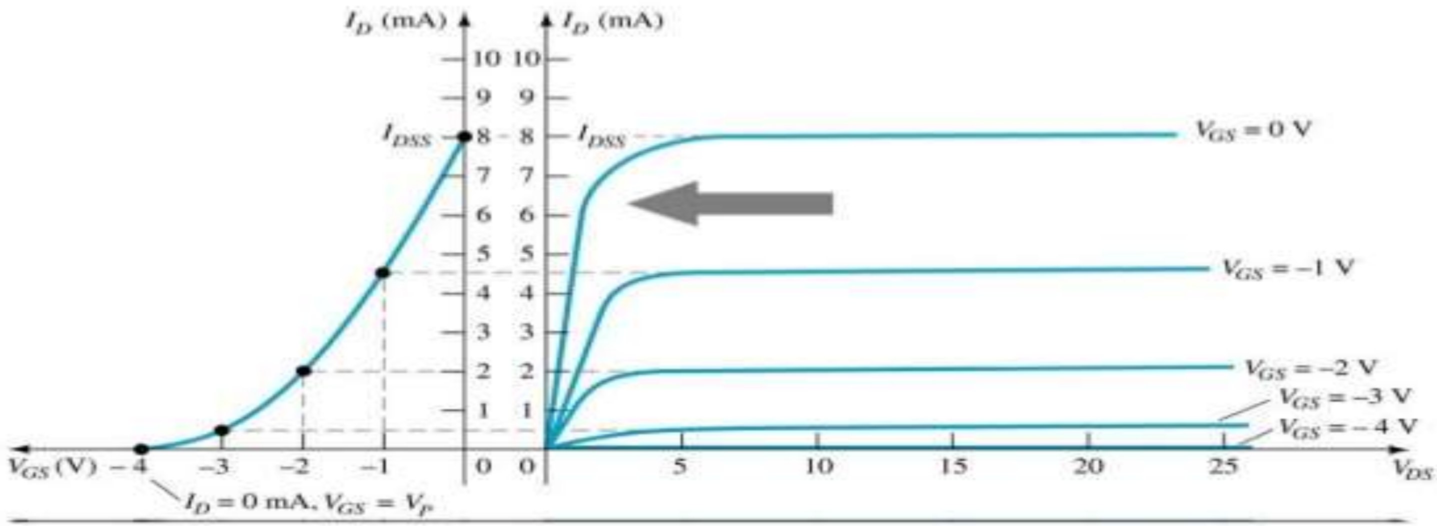
Pinch-off (V_{GS} = 0 V, $V_{DS} = V_P$).



OPERATION OF JFET(contd..)



JFET V-I AND TRANFERCHARACTERISTICS CURVE



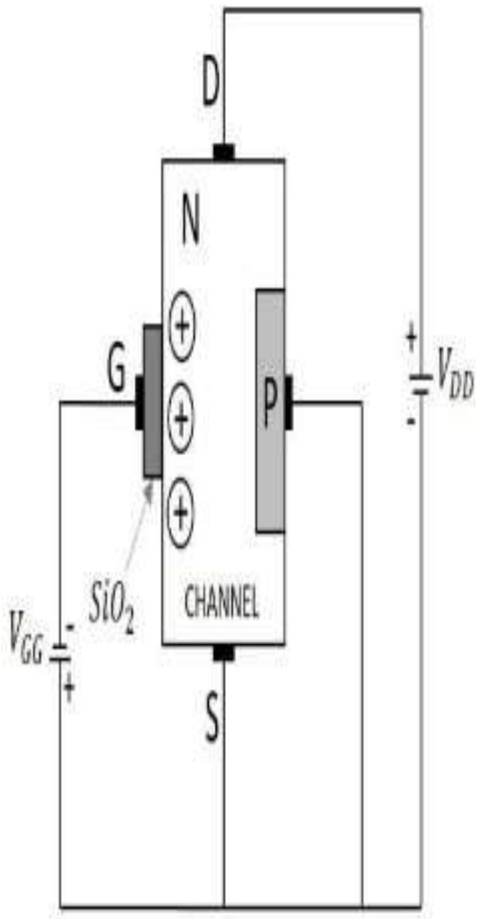
JFET Transfer Characteristic Curve

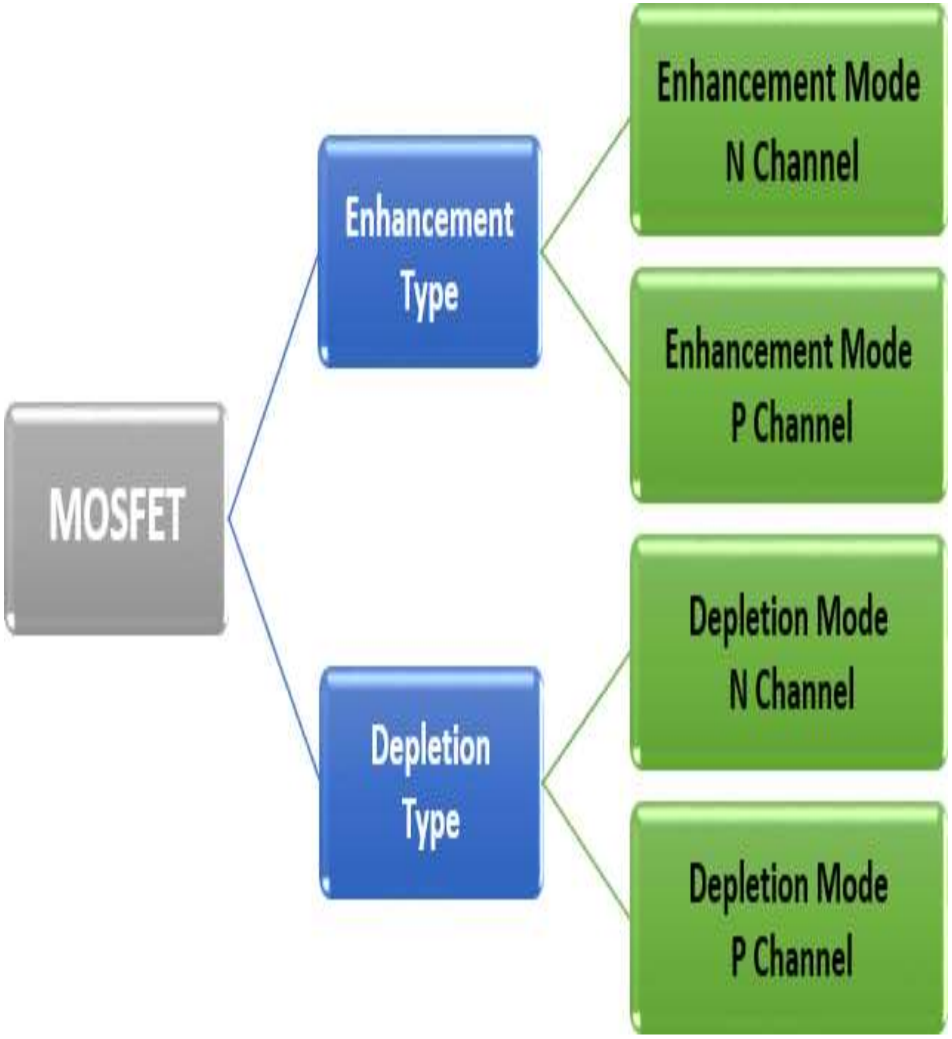
JFET Characteristic Curve

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.

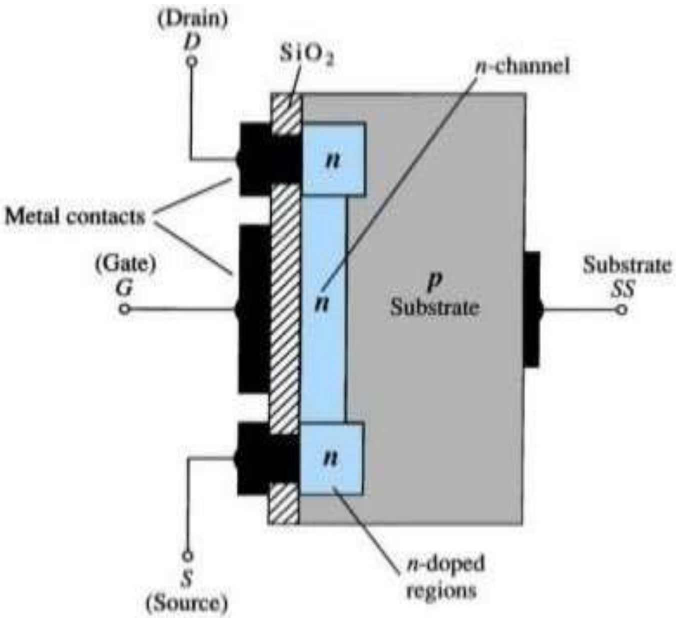
SYMBOL AND TYPES OF MOSFET

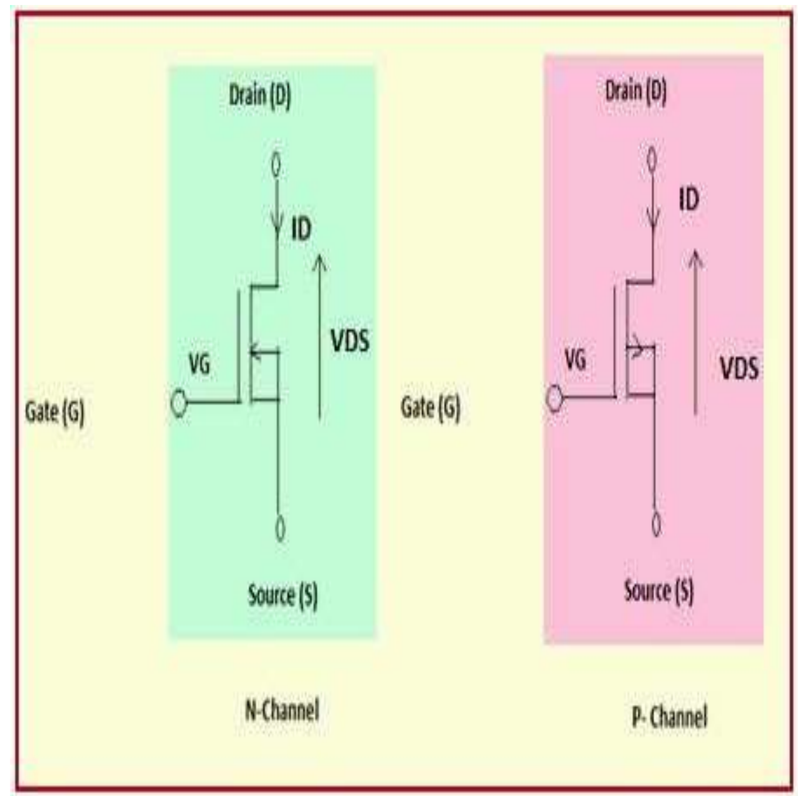




DEPLETION TYPE MOSFET

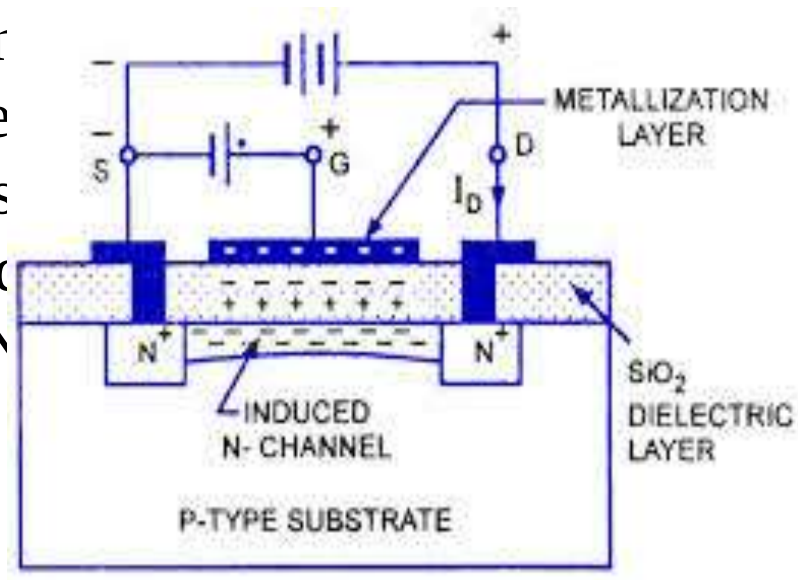
- When there is zero voltage on the gate terminal, the channel shows its maximum conductance. As the voltage on the gate is negative or positive, then decreases the channel conductivity.
- The Drain (D) and source (S) leads connect to the n – doped regions
- The n doped regions are connected by an N – 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.



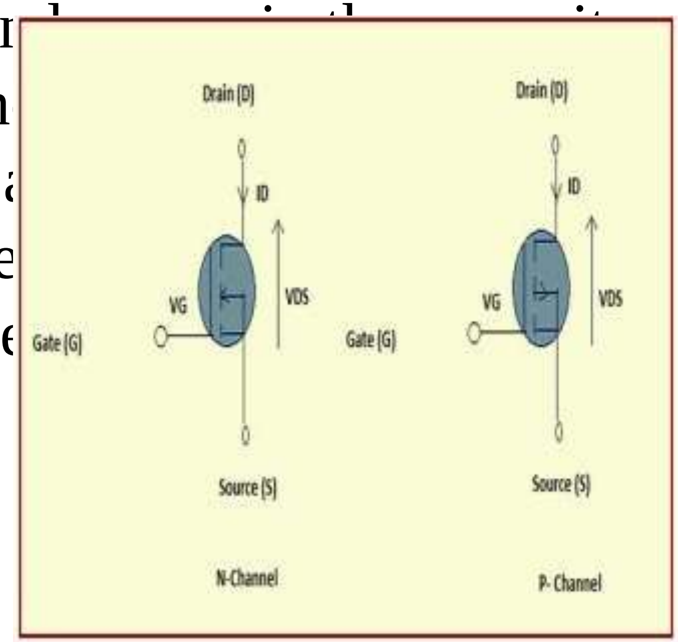


ENHANCEMENT TYPE MOSFET

- 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 char n ar type nn subs th a conc ele on N tive

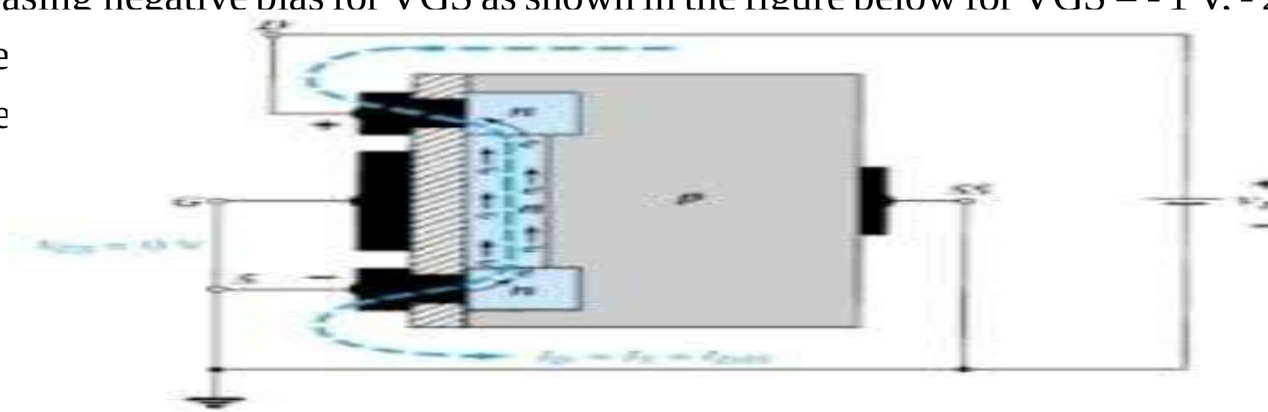


Operation of N-Channel E-MOSFET



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 figure
- 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 … of the transfer curve

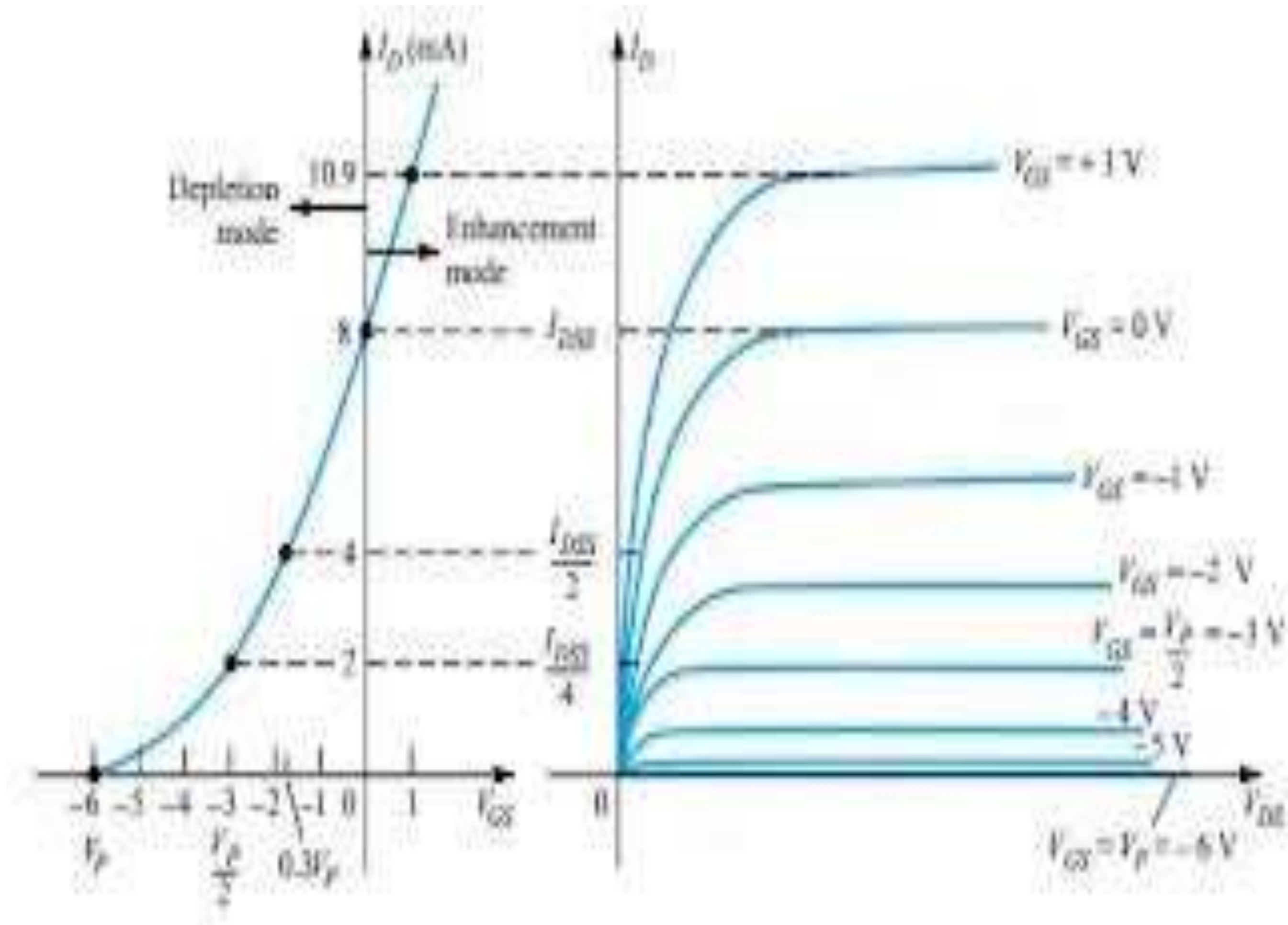


WORKING OF DEPLETION TYPE MOSFET(contd..)

- 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.

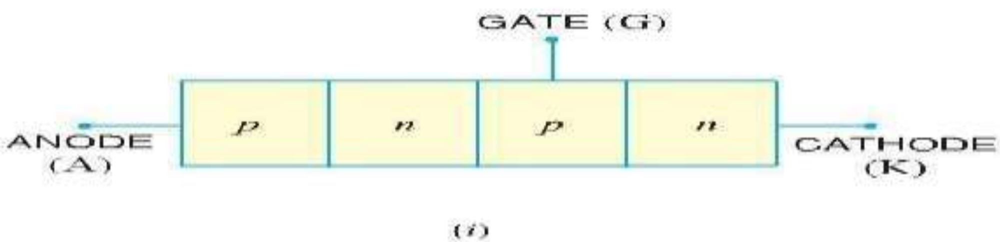
- The vertical spacing between the VGS = 0 V and VGS = 1 V curves in the characteristic curve is a clear indication of how much the current has increased for the 1-V change in VGS. Due to the rapid rise, the user must be aware of the maximum drain current rating since it could be exceeded with a positive 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 2mA, 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.

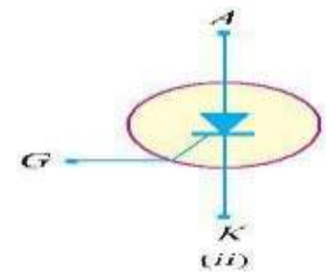
Drain and Transfer Characteristics of Depletion type MOSFET



SILICONCONTROLLED 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.
- *SCR* combines the features of a rectifier and a transistor.

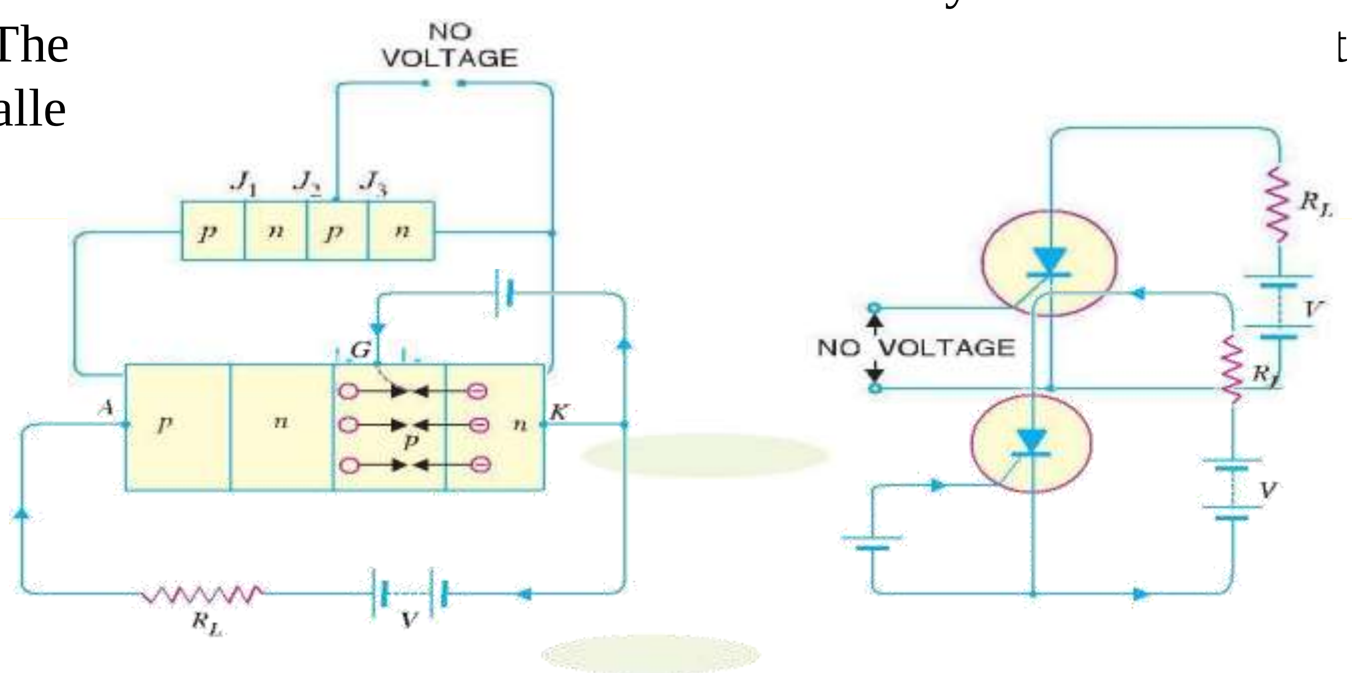




- When a PN junction is added to a junction transistor, the resulting three pn junction device is called a silicon controlled rectifier.
- Figure shows its construction.
- It is clear that it is essentially an ordinary rectifier (pn) and a junction transistor (npn) combined in one unit to form pnpn device.
- 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

WORKING OF SCR

- **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 t gate voltage is calle

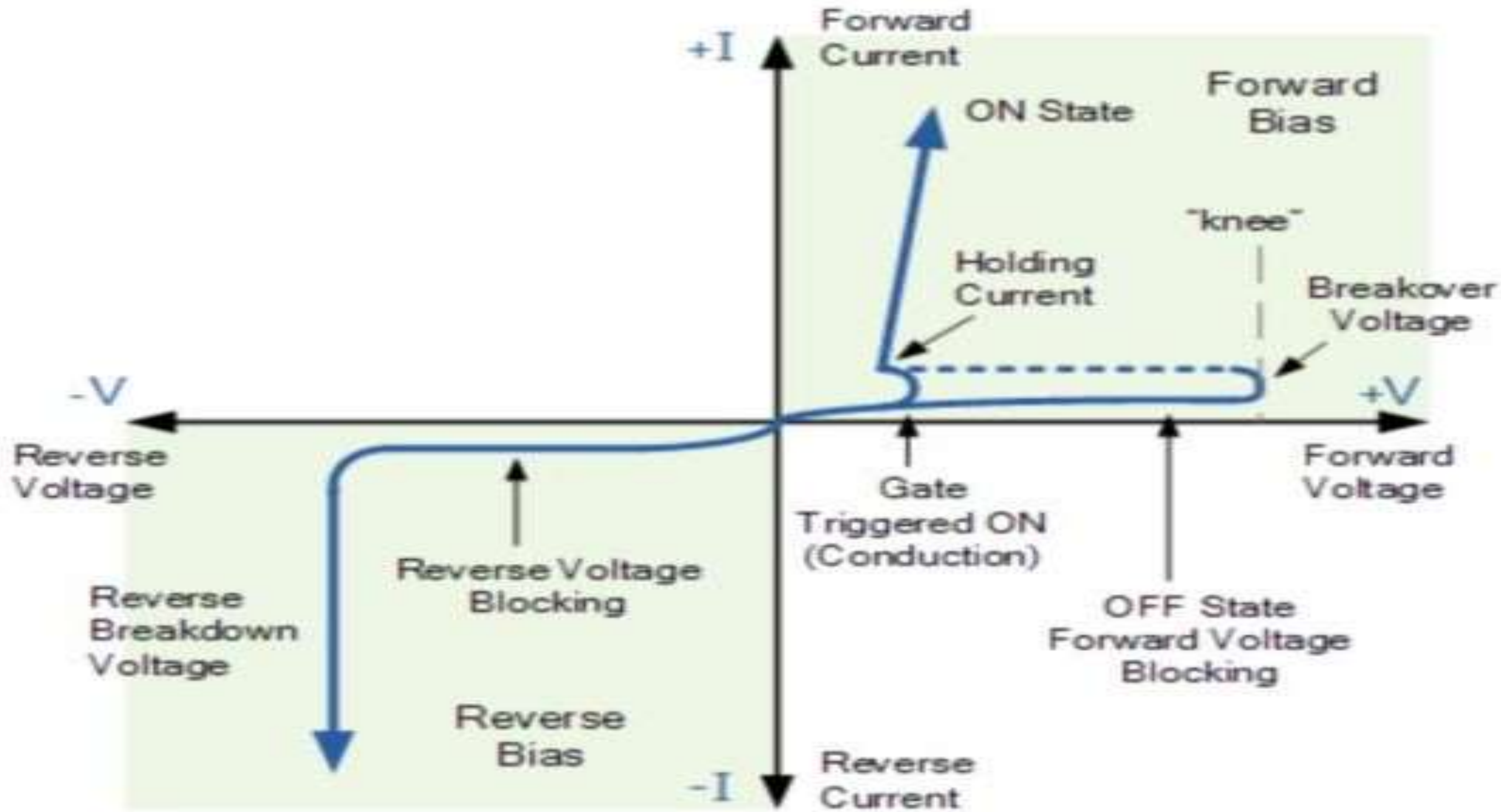


WORKING OF SCR(contd…)

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.

VI CHARACTERISTICS OF SCR



VI CHARACTERISTICS OF SCR(contd..)

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.

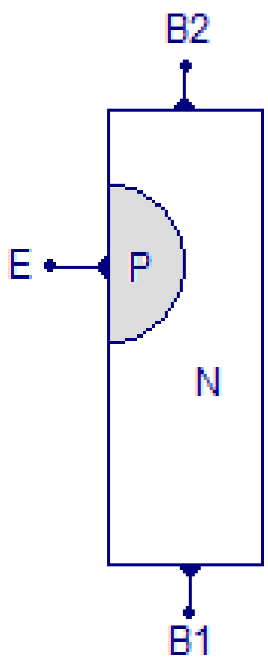
VI CHARACTERISTICS OF SCR(contd..)

Reverse blocking mode

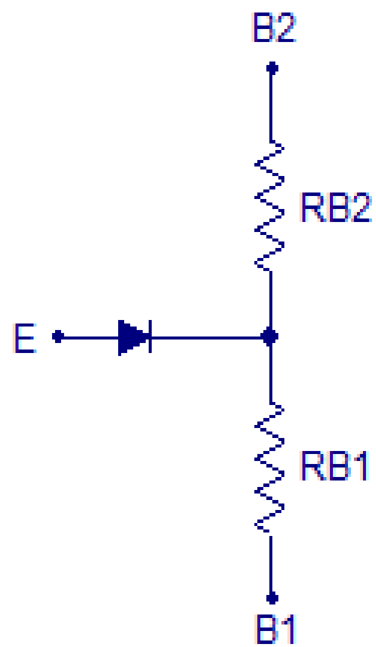
In this mode SCR is reversed biased , ie when anode is negative compared to cathode. The characteristic of this region are similar to those of an ordinary PN junction diode. in this region ,junctionJ1and J3 are reversed biased whereas j2 is forward biased the device behaves as if two diodes are connected 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.

UNI JUNCTION TRANSISTOR (UJT)

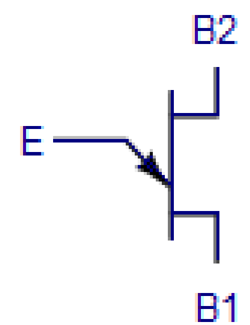
- A unijunction transistor (abbreviated as UJT) is a three-terminal semiconductor switching device. This device has a unique characteristic that when it is triggered, the emitter current increases regeneratively until it is limited by emitter power supply. Due to this characteristic, the unijunction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



UJT Internal block diagram

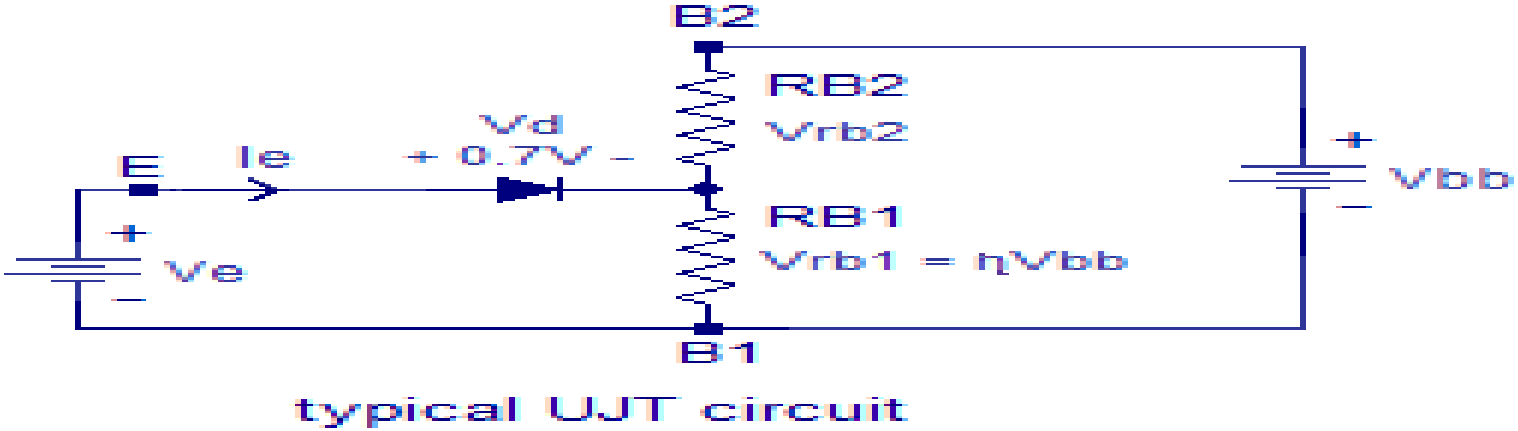


UJT simplified internal circuit model



UJT circuit symbol

WORKING 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

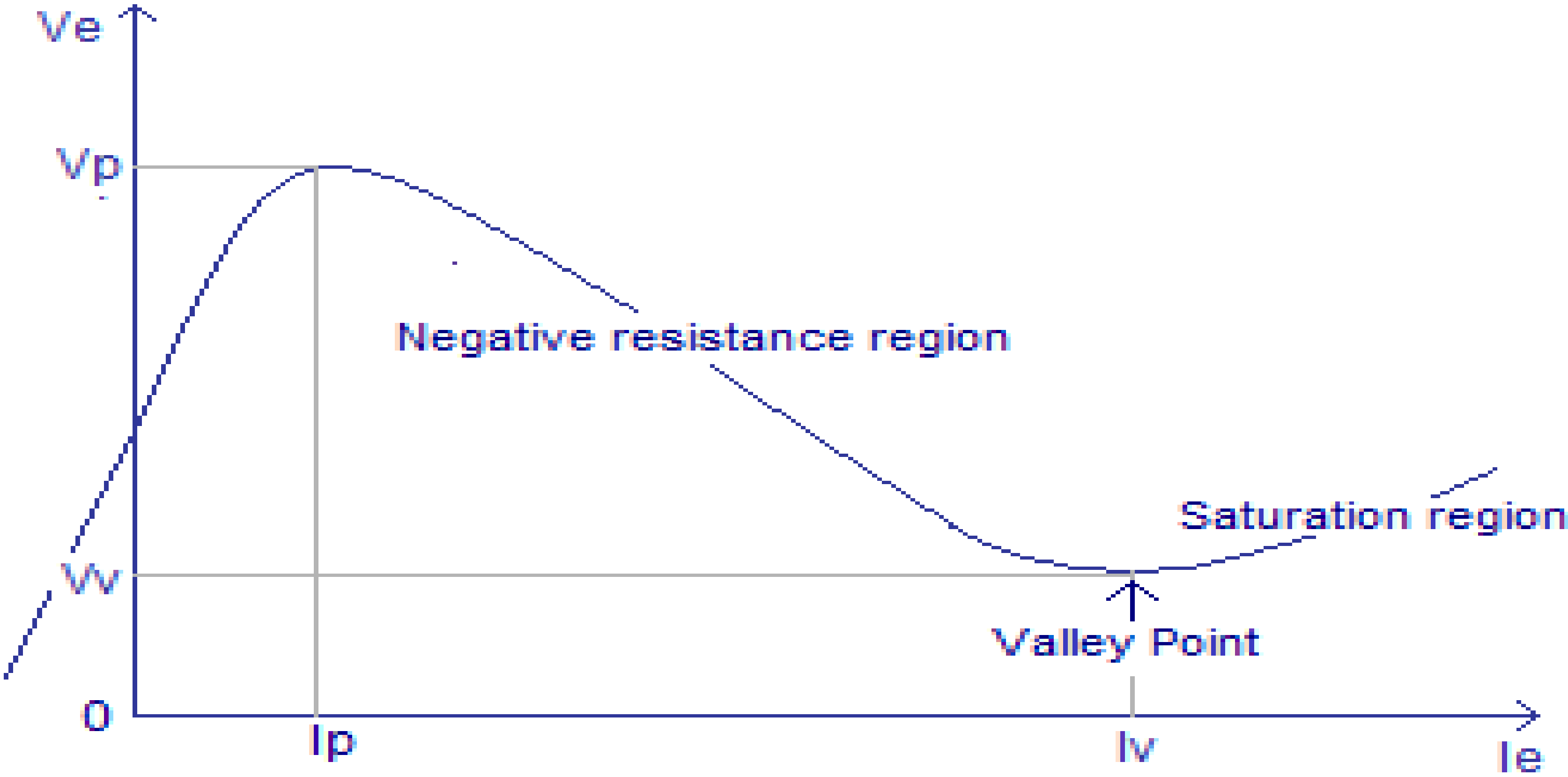
Vrb1 = Vbb* (RB1/(RB1+RB2))

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

CHARACTERISTICS OF UJT



UJT characteristics

CHARACTERISTICS OF UJT(contd..)

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.