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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND COMMMUNICATION ENGINEERING

UNIT - I
ELECTRONIC DEVICES – SECA1101

UNIT 1 SEMICONDUCTOR DIODE

PN junction diode- construction and operation

Current equations, Diffusion and drift current densities,

Forward and reverse bias characteristics,

Breakdown in PN Junction Diodes.

Applications- Rectifiers, Limiting and Clamping Circuits,

Zener diode- construction and VI characteristics.

CLASSIFICATION OF MATERIALS

Materials can be classified based on its conductivity property as

1.Conductor : material through which electric current can pass.

2.Semiconductor

3.Insulator :A material that does not easily transmit energy like electric Current

SEMICONDUCTOR

- Are the materials that partially conduct and partially does not conduct.
- Silicon and Germanium are best examples.
- Electronic devices like p-n diode, zener diode bipolar junction transistor.
- Classification of semiconductors

  1. intrinsic semiconductor

  2.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:

  1. number of electrons is equal to the number of holes. i.e., ne=nh.

2. electrical conductivity is low.

3. electrical conductivity of intrinsic semiconductors depends on their temperatures.

EXTRINSIC SEMICONDUCTORS

- Extrinsic semiconductor can be formed by adding impurity to intrinsic semiconductor.
- Properties:

1. the number of electrons is not equal to the number of holes. i.e., ne is not equal to nh.

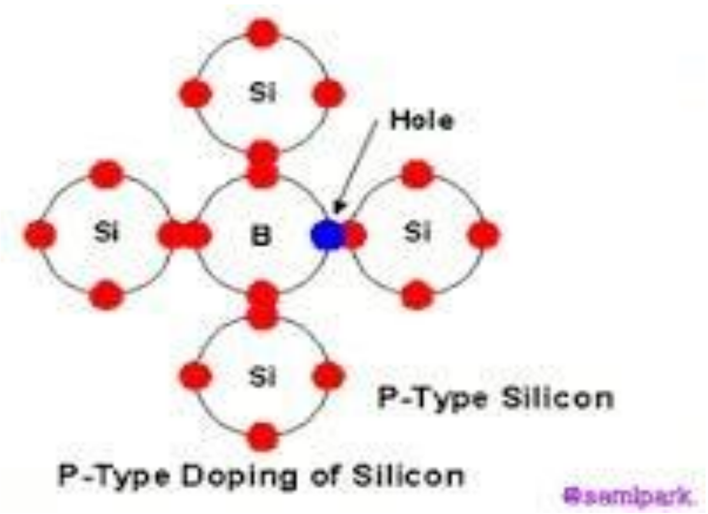
2. The electrical conductivity is high.

3. The electrical conductivity depends on the temperature and the amount of impurity added in them.

Extrinsic semiconductors

Pentavalent (n-type) Trivalent (p-type)

TRIVALENT(p-type)



- When a intrinsic semiconductor is added with Trivalent impurity it becomes a P-Type semiconductors.
- The P stands for Positive, which means the semiconductor is rich in holes or Positive charged ions.

- The total positive charge in a semiconductor is the sum of number of holes and number of donor atoms.

$$P+Nd\text{------}(1)$$

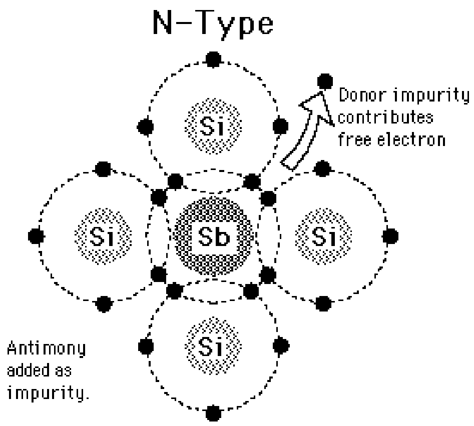
- The total negative charge in a semiconductor is the sum of number of electrons and number of acceptor atoms.

$$n+Na\text{ ------ }(2)$$

- At thermal equilibrium, total number of positive charge is equal to negative charge in a semiconductor i.e (1) = (2)

$$P+Nd= n+Na$$

N- Type



It is formed when a pentavalent impurity is added to intrinsic material.

N-type semiconductors have Negative charged ions or in other words have excess electrons.

Numbers of free electrons are greater than holes in the n- type semiconductor.

MASS ACTION LAW:

It states that at thermal equilibrium the product of the free electron concentration and the free hole concentration is equal to a constant irrespective of the number of donor atoms or number of acceptor atoms present in the semiconductor.

CHARGE DENSITY

- The charge density ρ (C/ m3) in a conductor is defined as the free charge per unit volume.

- The charge density in a metal is related to the density of free electrons, let n be the number of electrons per m^3 , the charge per electron is −q then the free charge per unit volume in the metal is given by

$$\rho = -nq$$

Drift and Diffusion Current

The total current that flows through a semiconductor has two components

1. Drift Current: is the flow due to the applied voltage across P-N junction, due to the diffusion of charge carriers. The diffusion current which flows from p – n region is balanced by opposite and equal drift current. The drift current is temperature dependent as the minority carriers are generated thermally. When an electric field is applied across the semiconductor material, the charge carriers attain a certain drift velocity. This combined effect of movement of the charge carriers constitutes a current known as "drift current". Drift current density due to the charge carriers such as free electrons and holes is the current passing through a square centimeter area perpendicular to the direction of flow.

Drift current density J_n , due to free electrons is given by

$$J_n = q\, n\, \mu_n\, E \text{ A / cm}^2$$

Drift current density J_P, due to holes is given by

$$J_P = q\, p\, \mu_p\, E \text{ A / cm}^2$$

Where, n - Number of free electrons per cubic centimeter.

P - Number of holes per cubic centimeter μ_n –

Mobility of electrons in cm^2 / Vs

μ_p – Mobility of holes in cm^2 / Vs

E – Applied Electric filed Intensity in V /cm

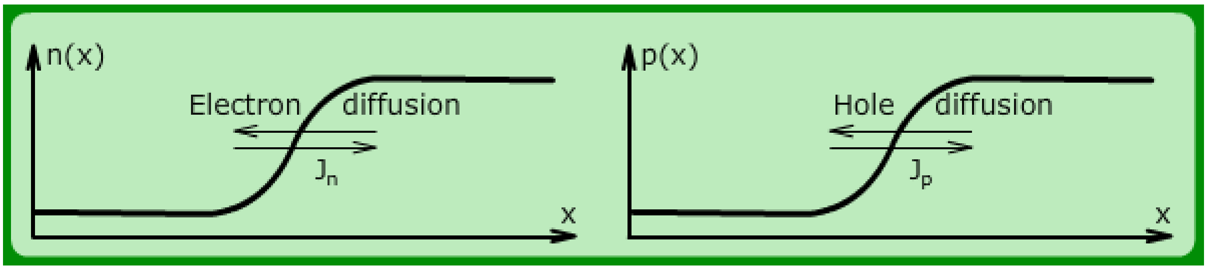
q – Charge of an electron = 1.6×10^{-19} coulomb.

DIFFUSION CURRENT

It is the process when a carrier concentration gradient exists in the semiconductor, through random motion, carriers will have a net movement from areas of high carrier concentration to areas of low concentration. This diffusion is dependent on time until hole- electron concentration is uniform without an external force being applied to the device. One-dimensional diffusion equations for electrons (n) and holes (p) can be written as follows:

where:

J_n and J_p = the diffusion current densities
q = electron charge
D_n and D_p = diffusion coefficients for electrons and holes
n and p = electron and hole concentrations

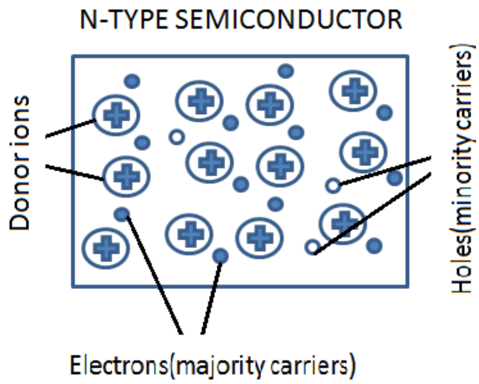


Diffusion currents due to carrier concentration gradient

PN JUNCTION THEORY

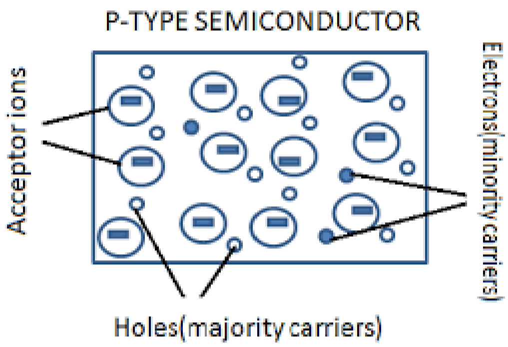
N- Type

In this type of semiconductor majority carriers are electrons and minority carriers are holes. N - type semiconductor is formed by adding pentavalent (five valence electrons) impurity in pure semiconductor crystal, e.g. P. As, Sb.



P-Type

In this type of semiconductor majority carriers are holes and minority carriers are electrons. P- type semiconductor is formed by adding trivalent (three valence electrons) impurity in pure semiconductor crystal, e.g. B, Al Ba.



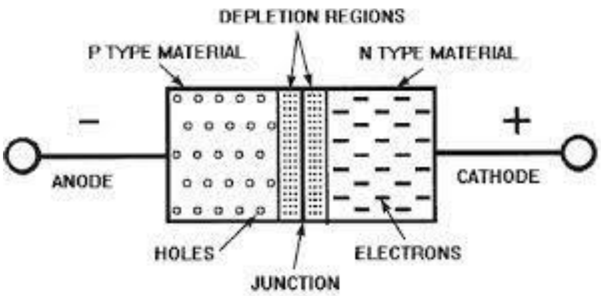
When these two semiconductors are fused then we obtain PN junction diode, when first joined together very large density gradient exists between both sides of the PN junction. Hence some of the free electrons from the donor impurity atoms begin to migrate across this newly formed junction to fill up the holes in the P-type material producing negative ions.

Due to the electrons crossing across the junction they leave behind positively charged donor ions (ND) on the negative side and now the holes from the acceptor impurity migrate across the junction in the opposite direction into the 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 (NA), and the charge density of the N- type along the junction becomes positive. This charge transfer of electrons and holes across the PN junction is known as diffusion. The width of these P and N layers depends on how heavily each side is doped with acceptor density NA, and donor density ND, respectively.

This process continues back and forth until the number of electrons which have crossed the junction have a large enough electrical charge to repel or prevent any more charge carriers from crossing over the junction. Eventually a state of equilibrium will occur producing a “potential barrier” zone around the area of the junction as the donor atoms repel the holes and the acceptor atoms repel the electrons.

Since no free charge carriers can rest in a position where there is a potential barrier, the regions on either sides of the junction now become completely depleted of any more free carriers in comparison to the N and P type materials further away from the junction. This area around the **PN Junction** is now called the Depletion Layer.



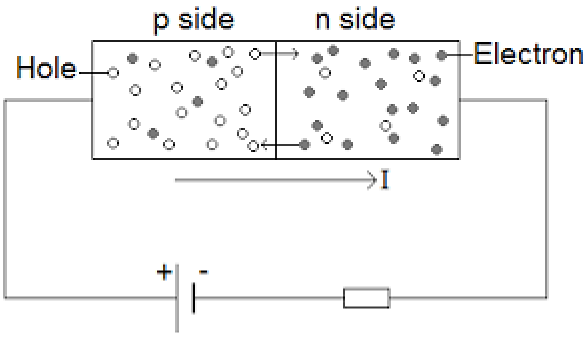
FORWARD BIASED OPERATION

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 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.

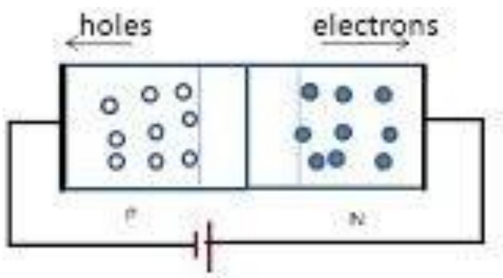
The external biasing causes a departure from the state of equilibrium and a misalignment of Fermi levels in the P and N regions, and also in the depletion layer.

The presence of two different Fermi levels in the depletion layer represents a state of quasi-equilibrium. The amount of charge Q stored in the diode is proportional to the current I flowing in the diode. 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.

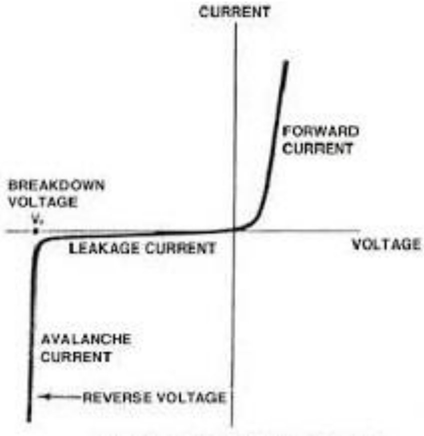


Reverse Bias Operation

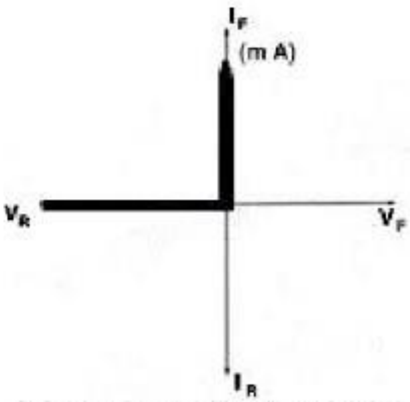
Positive terminal of the source is connected to the N side and the negative terminal is connected to P side. Here majority charge carriers are attracted away from the depletion layer by their respective battery terminals connected to PN junction. The Fermi level on N side is lower than the Fermi level on P side. 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



VI characteristics of diode



VI Characteristics of ideal diode

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The ability of an electron to drift under the influence of electric field is called Mobility.

CONDUCTIVITY

IF an electric field is applied to a metal then due to the electrostatic force, the electrons would be accelerated and the velocity would increase indefinitely if there would have been no collision with the ions. However at each collision with ion the electron loses some energy.

CLIPPER

An electronic device that is used to evade the output of a circuit to go beyond the preset value (voltage level) without varying the remaining part of the input waveform is called as clipper

WORKING OF CLIPPER CIRCUIT

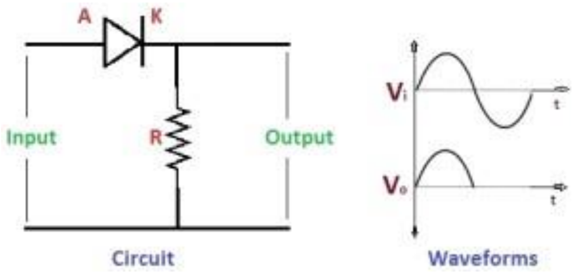
The clipper circuit can be designed by utilizing both the linear and nonlinear elements such as resistors, diodes or transistors. As these circuits are used only for clipping input waveform as per the requirement and for transmitting the waveform, they do not contain any energy storing element like a capacitor.

In general, clippers are classified into two types: Series Clippers and Shunt Clippers.

1. SERIES CLIPPERS

Series clippers are again classified into series negative clippers and series positive clippers which are as follows:

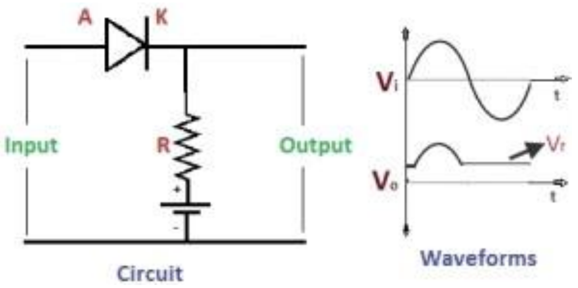
a. SERIES NEGATIVE CLIPPER



Series Negative Clipper

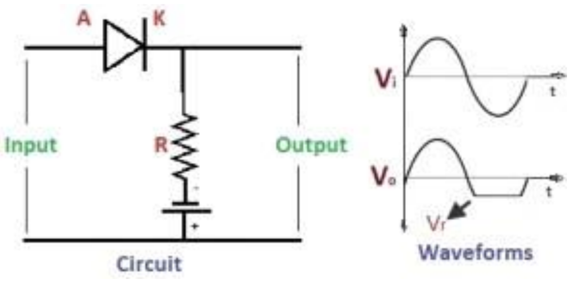
The above figure shows a series negative clipper with its output waveforms. During the positive half cycle the diode (considered as ideal diode) appears in the forward biased and conducts such that the entire positive half half cycle of input appears across the resistor connected in parallel as output waveform. During the negative half cycle the diode is in reverse biased. No output appears across the resistor. Thus, it clips the negative half cycle of the input waveform, and therefore, it is called as a series negative clipper.

Series Negative Clipper With Positive Vr



SERIES NEGATIVE CLIPPER WITH POSITIVE Vr

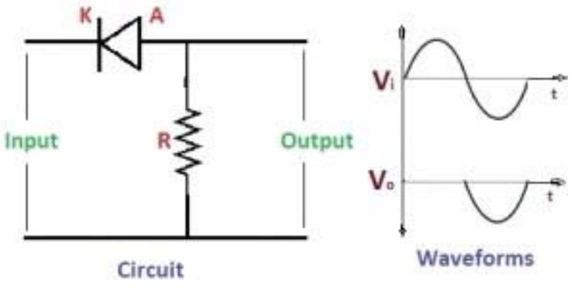
Series negative clipper with positive reference voltage is similar to the series negative clipper, but in this a positive reference voltage is added in series with the resistor. During the positive half cycle, the diode start conducting only after its anode voltage value exceeds the cathode voltage value. Since cathode voltage becomes equal to the reference voltage, the output that appears across the resistor will be as shown in the above figure.



SERIES NEGATIVE CLIPPER WITH NEGATIVE Vr

The series negative clipper with a negative reference voltage is similar to the series negative clipper with positive reference voltage, but instead of positive Vr here a negative Vr is connected in series with the resistor, which makes the cathode voltage of the diode as negative voltage. Thus during the positive half cycle, the entire input appears as output across the resistor, and during the negative half cycle, the input appears as output until the input value will be less than the negative reference voltage, as shown in the figure.

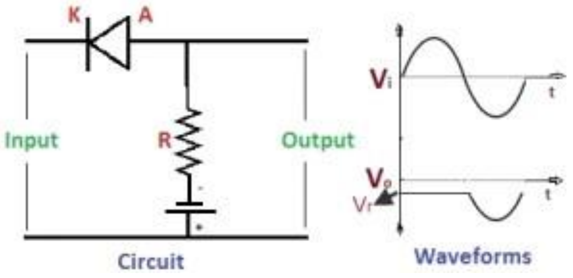
b. SERIES POSITIVE CLIPPER



Series Positive Clipper

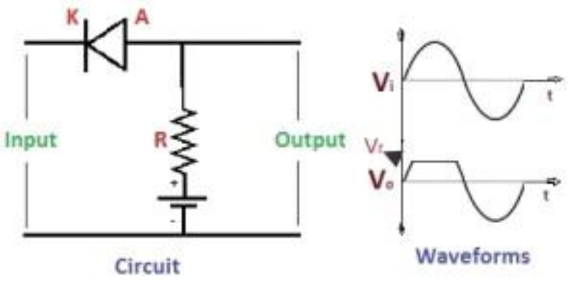
The series positive clipper circuit is connected as shown in the figure. During the positive half cycle, diode becomes reverse biased, and no output is generated across the resistor, and during the negative half cycle, the diode conducts and the entire input appears as output across the resistor.

Series Positive Clipper with Negative Vr



Series Positive Clipper with Negative Vr

It is similar to the series positive clipper in addition to a negative reference voltage in series with a resistor; and here, during the positive half cycle, the output appears across the resistor as a negative reference voltage. During the negative half cycle, the output is generated after reaching a value greater than the negative reference voltage, as shown in the above figure.



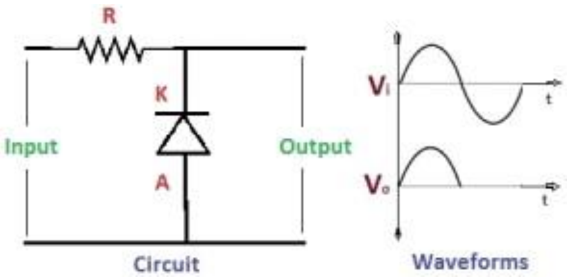
Series Positive Clipper with Positive Vr

Instead of negative reference voltage a positive reference voltage is connected to obtain series positive clipper with a positive reference voltage. During the positive half cycle, the reference voltage appears as an output across the resistor, and during the negative half cycle, the entire input appears as output across the resistor.

2. SHUNT CLIPPERS

Shunt clippers are classified into two types: shunt negative clippers and shunt positive clippers.

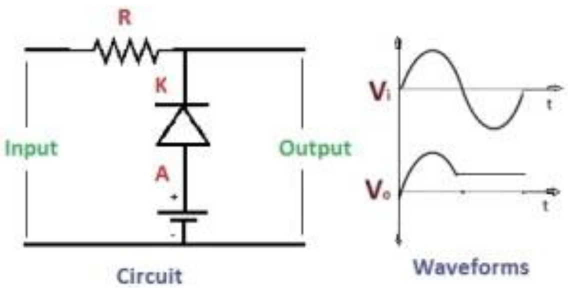
a. SHUNT NEGATIVE CLIPPER



Shunt Negative Clipper

Shunt negative clipper is connected as shown in the above figure. During the positive half cycle, the entire input is the output, and during the negative half cycle, the diode conducts causing no output to be generated from the input.

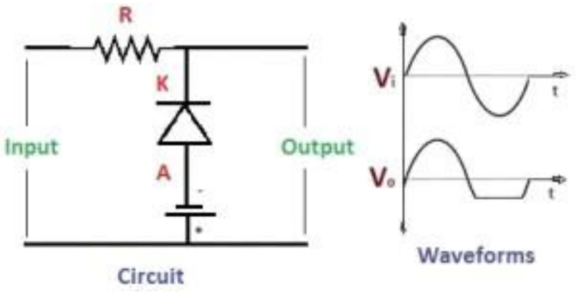
Shunt Negative Clipper with Positive Vr



Shunt Negative Clipper with Positive Vr

A series positive reference voltage is added to the diode as shown in the figure. During the positive half cycle, the input is generated as output, and during the negative half cycle, a positive reference voltage will be the output voltage as shown above.

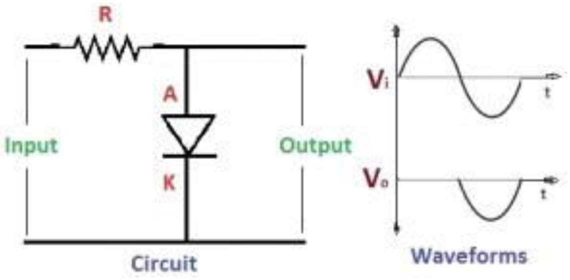
Shunt Negative Clipper with Negative Vr



Shunt Negative Clipper with Negative Vr

Instead of positive reference voltage, a negative reference voltage is connected in series with the diode to form a shunt negative clipper with a negative reference voltage. During the positive half cycle, the entire input appears as output, and during the negative half cycle, a reference voltage appears as output as shown in the above figure.

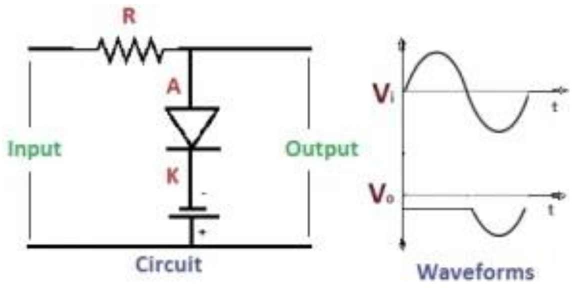
b. SHUNT POSITIVE CLIPPER



Shunt Positive Clipper

During the positive half cycle the diode is in conduction mode and no output is generated; and during the negative half cycle; entire input appears as output as the diode is in reverse bias as shown in the above figure.

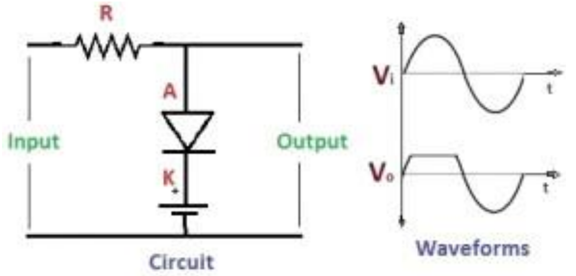
SHUNT POSITIVE CLIPPER WITH NEGATIVE Vr



SHUNT POSITIVE CLIPPER WITH NEGATIVE Vr

During the positive half cycle, the negative reference voltage connected in series with the diode appears as output; and during the negative half cycle, the diode conducts until the input voltage value becomes greater than the negative reference voltage and output will be generated as shown in the figure.

SHUNT POSITIVE CLIPPER WITH POSITIVE Vr

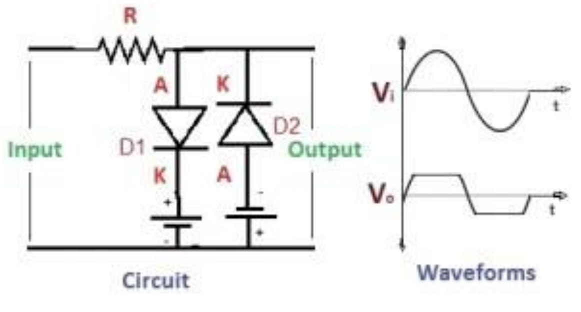


Shunt Positive Clipper with Positive Vr

During the positive half cycle the diode conducts causing the positive reference voltage appear as output voltage; and, during the negative half cycle, the entire input is generated as the output as the diode is in reverse biased.

In addition to the positive and negative clippers, there is a combined clipper which is used for clipping both the positive and negative half cycles as discussed below.

Positive-Negative Clipper with Reference Voltage Vr



Positive-Negative Clipper with Reference Voltage Vr

The circuit is connected as shown in the figure with a reference voltage Vr, diodes D1 & D2. During the positive half cycle, the diode the diode D1 conducts causing the reference voltage connected in series with D1 to appear across the output.

During the negative cycle, the diode D2 conducts causing the negative reference voltage connected across the D2 appear as output, as shown in the above figure.

Clippers find several applications, such as

- They are frequently used for the separation of synchronizing signals from the composite picture signals.
- The excessive noise spikes above a certain level can be limited or clipped in FM transmitters by using the series clippers.
- For the generation of new waveforms or shaping the existing waveform, clippers are used.
- The typical application of diode clipper is for the protection of transistor from transients, as a freewheeling diode connected in parallel across the inductive load.
- Frequently used half wave rectifier in power supply kits is a typical example of a clipper. It clips either positive or negative half wave of the input.
- Clippers can be used as voltage limiters and amplitude selectors.

CLAMPERS

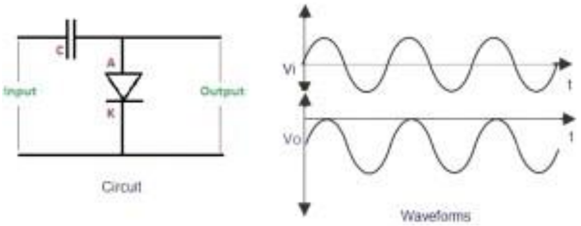
An electronic circuit that is used to alter the positive peak or negative peak of the input signal to a definite value by shifting the entire signal up or down to obtain the output signal peaks at desired level is called as Clamper circuit.

WORKING OF CLAMPER CIRCUIT

The positive or negative peak of a signal can be positioned at the desired level by using the clamping circuits. As we can shift the levels of peaks of the signal by using a clamper, hence, it is also called as level shifter.

The clamper circuit consists of a capacitor and diode connected in parallel across the load. The clamper circuit depends on the change in the time constant of the capacitor. The capacitor must be chosen such that, during the conduction of the diode, the capacitor must be sufficient to charge quickly and during the non-conducting period of diode, the capacitor should not discharge drastically. The clampers are classified as positive and negative clampers based on the clamping method.

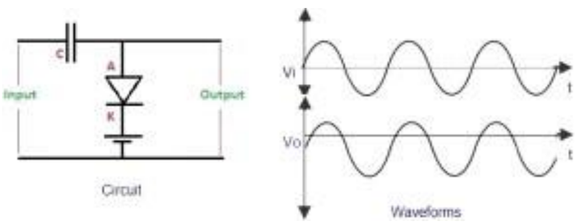
1. NEGATIVE CLAMPER



Negative Clamper

During the positive half cycle, the input diode is in forward bias- and as the diode conducts- capacitor gets charged (up to peak value of input supply). During the negative half cycle, reverse does not conduct and the output voltage become equal to the sum of the input voltage and the voltage stored across the capacitor.

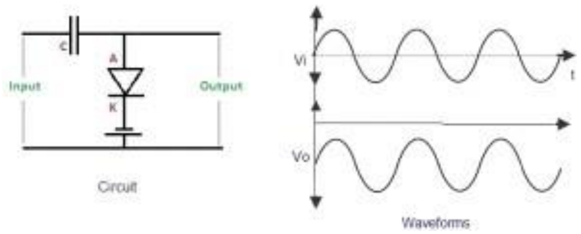
Negative Clamper with Positive Vr



NEGATIVE CLAMPER WITH POSITIVE Vr

It is similar to the negative clamper, but the output waveform is shifted towards the positive direction by a positive reference voltage. As the positive reference voltage is connected in series with the diode, during the positive half cycle, even though the diode conducts, the output voltage becomes equal to the reference voltage; hence, the output is clamped towards the positive direction as shown in the above figure.

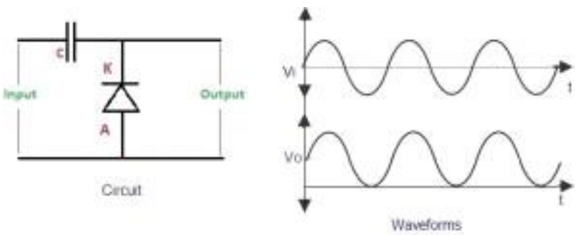
Negative Clamper with Negative Vr



NEGATIVE CLAMPER WITH NEGATIVE Vr

By inverting the reference voltage directions, the negative reference voltage is connected in series with the diode as shown in the above figure. During the positive half cycle, the diode starts conduction before zero, as the cathode has a negative reference voltage, which is less than that of zero and the anode voltage, and thus, the waveform is clamped towards the negative direction by the reference voltage value.

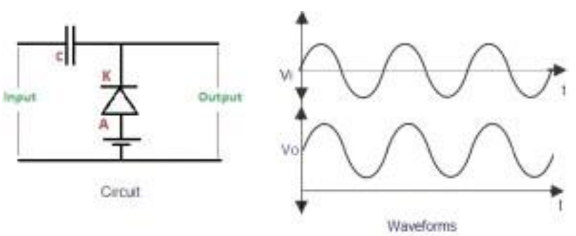
2. POSITIVE CLAMPER



POSITIVE CLAMPER

It is almost similar to the negative clamper circuit, but the diode is connected in the opposite direction. During the positive half cycle, the voltage across the output terminals becomes equal to the sum of the input voltage and capacitor voltage (considering the capacitor as initially fully charged). During the negative half cycle of the input, the diode starts conducting and charges the capacitor rapidly to its peak input value. Thus the waveforms are clamped towards the positive direction as shown above.

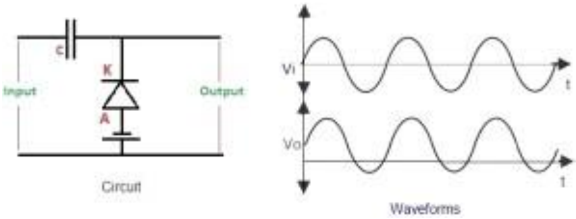
Positive Clamper with Positive Vr



POSITIVE CLAMPER WITH POSITIVE Vr

A positive reference voltage is added in series with the diode of the positive clamper as shown in the circuit. During the positive half cycle of the input, the diode conducts as initially the supply voltage is less than the anode positive reference voltage. If once the cathode voltage is greater than anode voltage then the diode stops conduction. During the negative half cycle, the diode conducts and charges the capacitor. The output is generated as shown in the figure.

POSITIVE CLAMPER WITH NEGATIVE Vr



Positive Clamper with Negative Vr

The direction of the reference voltage is reversed, which is connected in series with the diode making it as a negative reference voltage. During the positive half cycle the diode will be non conducting, such that the output is equal to capacitor voltage and input voltage. During the negative half cycle, the diode starts conduction only after the cathode voltage value becomes less than the anode voltage. Thus, the output waveforms are generated as shown in the above figure.

.**Clampers can be used in applications**

- The complex transmitter and receiver circuitry of television clamper is used as a base line stabilizer to define sections of the luminance signals to preset levels.
- Clampers are also called as direct current restorers as they clamp the wave forms to a fixed DC potential.
- These are frequently used in test equipment, sonar and radar systems.
- For the protection of the amplifiers from large errant signals clampers are used.
- Clampers can be used for removing the distortions
- For improving the overdrive recovery time clampers are used.

ZENER DIODE

A Zener diode is a type of diode that permits current not only in the forward direction like a normal diode, but also in the reverse direction if the voltage is larger than the breakdown voltage known as "Zener knee voltage" or "Zener voltage". The device was named after Clarence Zener, who discovered this electrical property.

Diode symbol

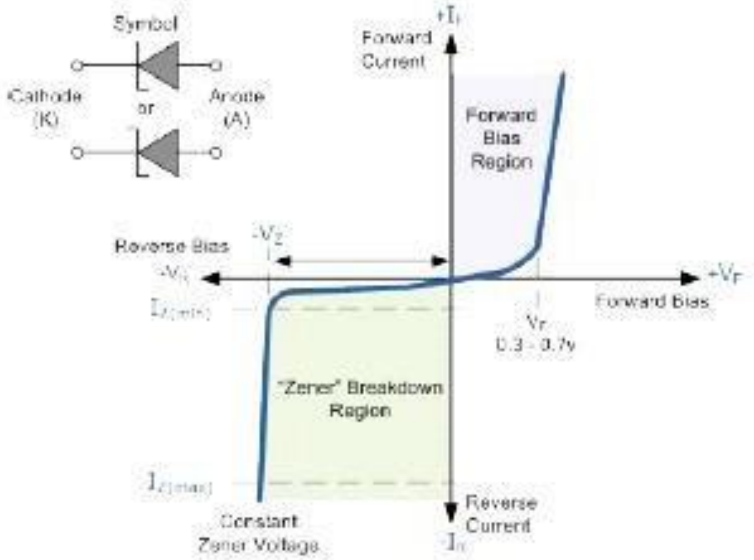
However, the Zener Diode or "Breakdown Diode" as they are sometimes called, are basically the same as the standard PN junction diode but are specially designed to have a low pre-determined Reverse Breakdown Voltage that takes advantage of this high reverse voltage. The point at which a zener diode breaks down or conducts is called the "Zener Voltage" (Vz).

The Zener diode is like a general-purpose signal diode consisting of a silicon PN junction. When biased in the forward direction it behaves just like a normal signal diode passing the rated current, but when a reverse voltage is applied to it the reverse saturation current remains fairly constant over a wide range of voltages. The reverse voltage increases until the diodes breakdown voltage VB is reached at which point a process called Avalanche Breakdown occurs in the depletion layer and the current flowing through the zener diode increases dramatically to the maximum current value (which is usually limited by a series resistor). This breakdown voltage point is called the "zener voltage" for zener diodes.

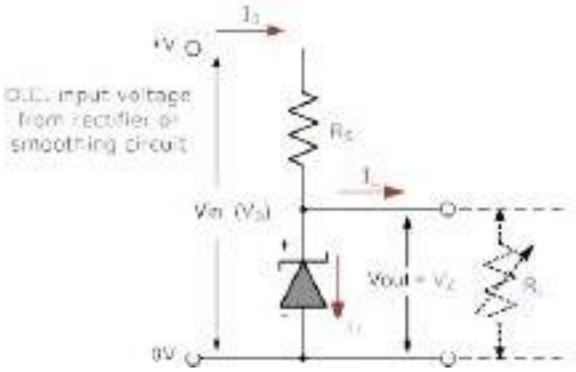
The point at which current flows can be very accurately controlled (to less than 1% tolerance) in the doping stage of the diodes construction giving the diode a specific *zener breakdown voltage*, (Vz) ranging from a few volts up to a few hundred volts. This zener breakdown voltage on the I-V curve is almost a vertical straight line.

ZENER DIODE CHARACTERISTICS

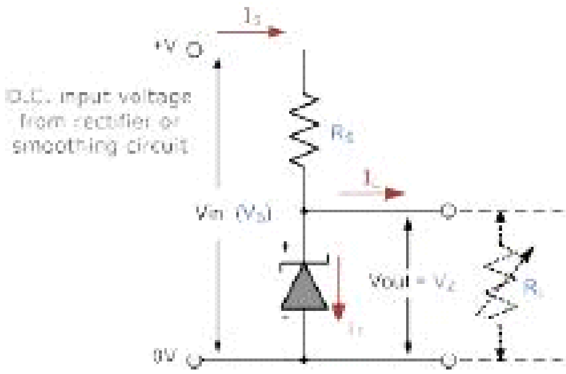
The Zener Diode is used in its "reverse bias" or reverse breakdown mode, i.e. the diodes anode connects to the negative supply. From the I-V characteristics curve above, we can see that the zener diode has a region in its reverse bias characteristics of almost a constant negative voltage regardless of the value of the current flowing through the diode and remains nearly constant even with large changes in current as long as the zener diodes current remains between the breakdown current IZ(min) and the maximum current rating IZ(max).

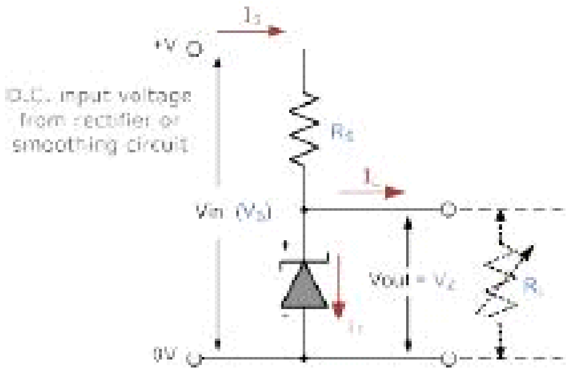


THE ZENER DIODE REGULATOR



Zener Diodes can be used to produce a stabilised voltage output with low ripple under varying load current conditions. By passing a small current through the diode from a voltage source, via a suitable current limiting resistor (RS), the zener diode will conduct sufficient current to maintain a voltage drop of Vout. We remember from the previous tutorials that the DC output voltage from the half or full- wave rectifiers contains ripple superimposed onto the DC voltage and that as the load value changes so to does the average output voltage. By connecting a simple zener stabiliser circuit as shown below across the output of the rectifier, a more stable output voltage can be produced**.**





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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND COMMMUNICATION ENGINEERING

UNIT - II
ELECTRONIC DEVICES – SECA1101

UNIT 2 BIPOLAR JUNCTION TRANSISTOR

Bipolar junction transistors, NPN -PNP, construction, forward and reverse bias characteristics - Early effect, current equations- Input and Output characteristics of CE, CB CC- Ebers Moll Model- Multi Emitter Transistor, Gummel Poon-model.

Unit-II BIPOLAR JUNCTION TRANSISTOR

INTRODUCTION

- **The transistor was developed by Dr.Shockley along with Bell Laboratories team in 1951**
- **The transistor is a main building block of all modern electronic systems**
- **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**
- **An amplifier is a circuit that is used to increase the strength of an ac signal**
- **Basically there are two types of transistors**
    - **Bipolar junction transistor**
    - **Field effect transistor**
- **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**

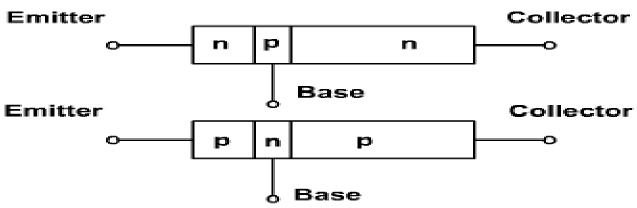


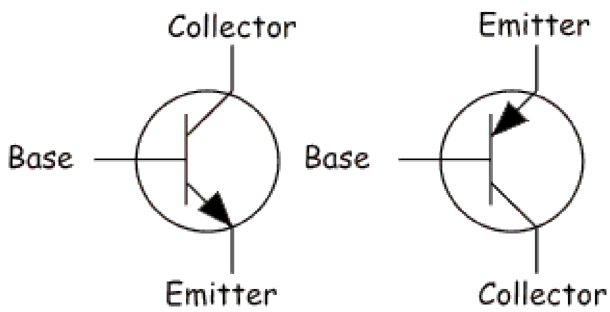
Fig: transistor

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 alightly 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 carrirs**
- **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



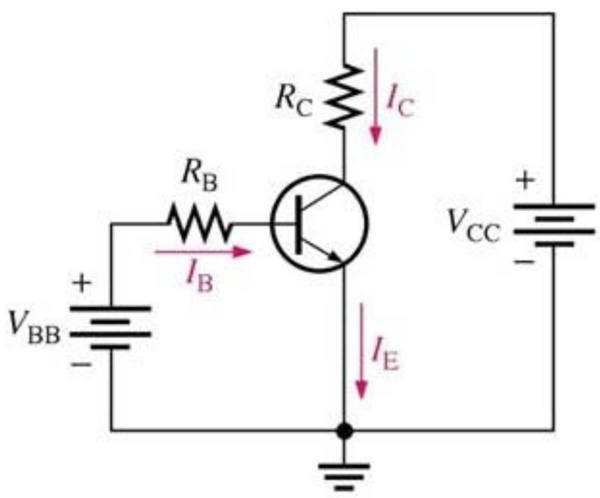
- **The transistor symbol carries an arrow head in the emitter pointing from the P-region towards the N- region**
- **The arrow head indicates the direction of a conventional current flow in a transistor**
- **The direction of arrow heads at the emitter in NPN and PNP transistor is opposite to each other**
- **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 the 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



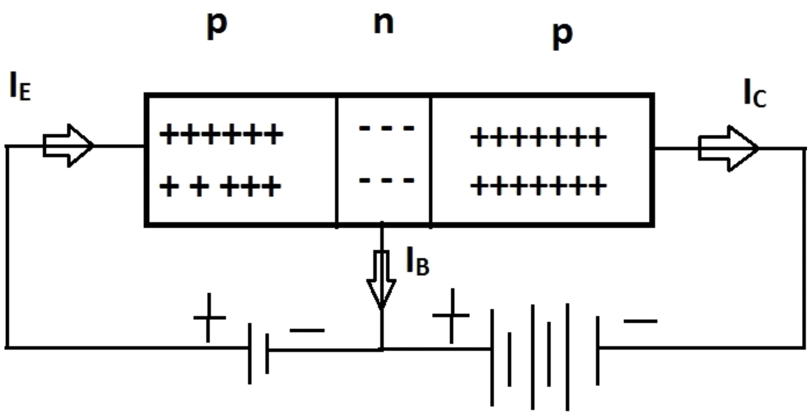
(a) *npn*

- 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 . 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 electron combine with holes in the base, they constitute base current ().**
- **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 . 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



p-n-p 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 ( ).
- The holes after reaching the base region, combine with the electrons in the base and constitutes base current.
- 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 region
- 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 called reverse saturation current.

TRANSISTOR CURRENTS

- **We know that direction of conventional current is always opposite to the electron current in any electronic device.**
- **However, the direction of a conventional current is same as that of a hole current in a PNP transistor**
- **Emitter current**
- **Base current**
- **Collector current**

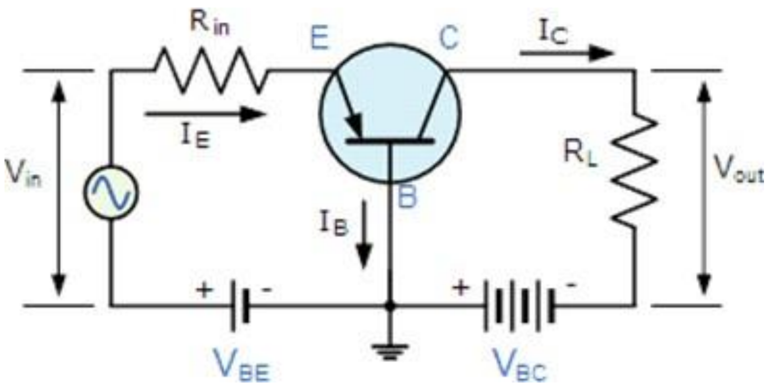
- **Since the base current is very small**

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.**
- **If there is no input ac signal, then the ratio of collector current to emitter current   is called dc alpha**
- **The ratio of change in the collector current to change in the emitter current is known as ac alpha**

   = Common-emitter current gain   = Common-base current gain

$$= \frac{I_C}{I_B} \qquad\qquad = \frac{I_C}{I_E}$$

- **The input characteristics look like the characteristics of a forward-biased diode. Note that V_{BE} varies only slightly, so we often ignore these characteristics and assume:**

- Common approximation: $V_{BE} = V_o = 0.65$ to $0.7V$

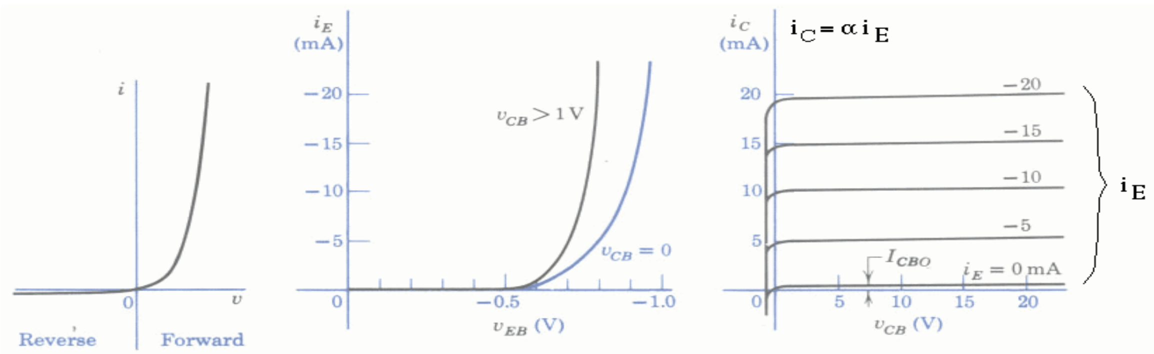
- The higher the value of better the transistor. It can be increased by making the base thin and lightly doped

- The collector current consists of two parts transistor action. Ie., component dependind upon the emitter current , which is produced by majority carriers

- The leakage current due to the movement of the minority carriers across base collector junction

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



(a) Diode characteristic (b) Emitter characteristics (c) Collector 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 characteristics

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

- increase 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 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
  - The emitter current increases rapidly with small increase in which means low input resistance
  - Because input resistance of a transistor is the reciprocal of the slope of the input characteristics

Output characteristics

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

ACTIVE REGION

- There is a very small increase in with increase in
- This is because the increase in expands the collector – base depletion region and shorten the distance between two depletion region
- Hence due to the early effect does not increase very much with increase in
- Although, the collector current is independent of if is increased beyond a certain value, eventually increases rapidly because of avalanche effects
- This condition is called punch – through or reach – through
- When it occurs large current can flow destroying the device

CUT – OFF REGION

- small collector current flows even when emitter current
- this is the collector leakage current

SATURATION REGION

- collector current flows even when the external applied voltage is reduced to zero. There is a low barrier potential existing at the collector – base junction and this assists in the flow of collector current

(II) COMMON – EMITTER CONFIGURATION

- **The input is connected between base and emitter, while output is connected between collector and emitter**
- **Emitter us 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.**
- **CE is commonly used because its current, Voltage, Power gain are quite high nd output to input impedance ratio is moderate**
- **The rate of change in collector current to change in base current is called amplification factor B.**
- **The current gain in the common-emitter circuit is called BETA (b). Beta is the relationship of collector current (output current) to base current (input current).**
- **Two voltages are applied respectively to the base** B **and collector** C **with respect to the common emitter** E**.**
- **Same as the CB configuration, here in the CE configuration, the BE junction is forward biased while the CB junction is reverse biased. The voltages of CB and CE configurations are related by:**

$$V_{CE} = V_{CB} + V_{BE}, \quad \text{or} \quad V_{CB} = V_{CE} - V_{BE}$$

- **The base current is treated as the input current, and the collector current is treated as the output current:**

$$I_C = \alpha I_E + I_{CB0} = \alpha(I_C + I_B) + I_{CB0} \approx \alpha(I_C + I_B)$$

- **Solving this equation for collector current, we get the relationship between the output collector current and the input base current:**

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CB0} = \beta I_B + (\beta+1) I_{CB0} = \beta I_B + I_{ce0} \approx \beta I_B$$

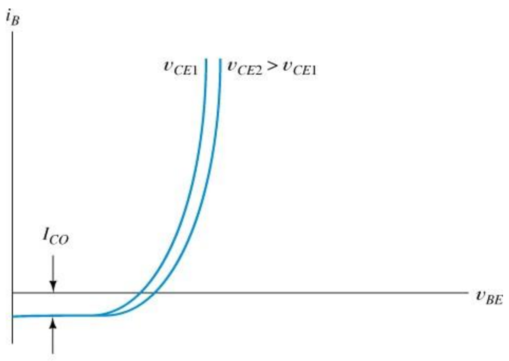
- **Here we have also defined the CE *current gain* or *current transfer ratio***

$$\beta = \frac{\alpha}{1-\alpha} \approx \frac{I_C}{I_B}$$

- **which is approximately the ratio of the output current and the input current . The two parameters α and β are related by:**

$$\beta = \frac{\alpha}{1-\alpha}, \qquad \alpha = \frac{\beta}{1+\beta}, \quad 1+\beta = \frac{1}{1-\alpha}, \qquad 1-\alpha = \frac{1}{1+\beta}$$

Characteristics of CE configuration



(a) Input characteristics

i) Input Characteristics

- **Same as in the case of common-base configuration, the junction of the common-emitter configuration can also be considered as a forward biased diode, the current-voltage characteristics is similar to that of a diode:**

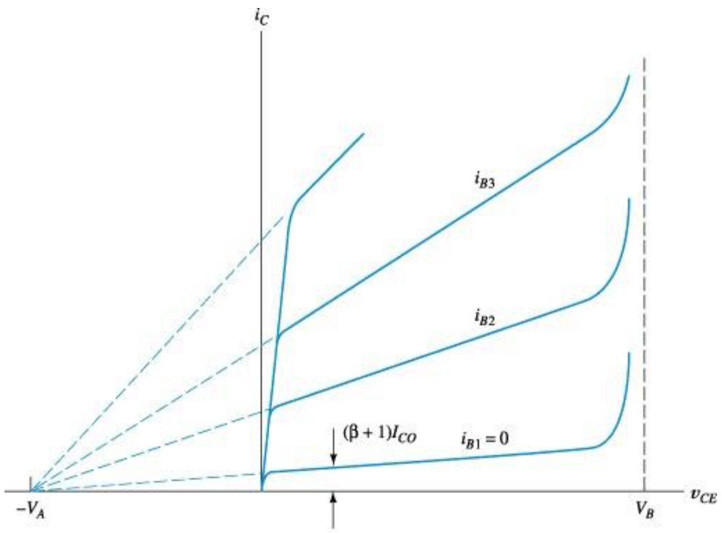
$$I_B = f(V_{BE}, V_{CE}) \approx f(V_{BE}) = I_0 (e^{V_{BE}/V_T} - 1)$$

- **The Curve drawn between base current and base-emitter voltage for a given value of collector-emitter voltage is known as input characteristics.**
- **The input characteristics of CE transistors are similar to those of a forward biased diode because the base-emitter region of the transistor is forward-biased.**
- **Input Resistance is larger in CE configuration than in CB configuration.**

This is because the I/P current increases less rapidly with increase in Vbe.

- An increment in value of Vce causes the input current to be lower for a given level of Vbe.
- This is explained on the basis of early effect.
- As a result of early effect, more charge carriers from the emitter flows across the collector-base junction and flow out through the based lead.

ii) Output Characteristics



(b) Output characteristics

$$I_C = f(I_B, V_{CE}) \approx f(I_B) = \beta I_B \qquad \text{(in linear region)}$$

- It is the curve drawn between collector current Ic and collector-emitter voltage Vce for a given value of base current Ib.

- The collector current Ic varies with Vce and becomes a constant.
- Output characteristics in CE configuration has some slope while CB configuration has almost horizontal characteristics.
- This indicates that output resistance incase of CE configuration is less than that in CB configuration.

Active Region

- For small values of base current, the effect of collector voltage Vc over Ic is small but for large values of Ib, this effect increases.
- The shape of the characteristic is same as CB configuration
- The difference that Ic is larger than input current

- **Thus, the current gain is greater than unity.**

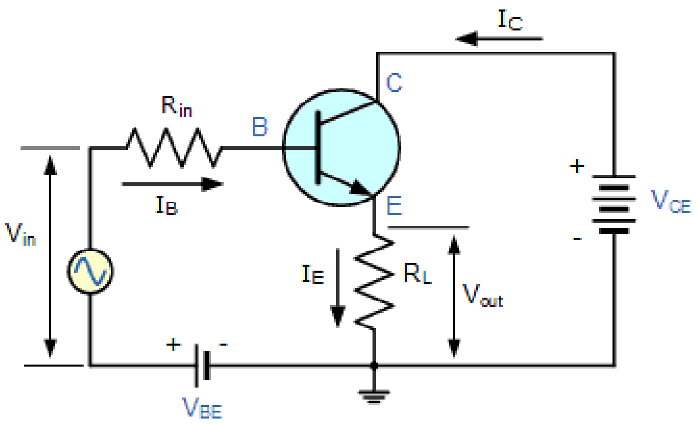
<u>Saturation Region</u>

- **With low values of Vce, the transistor is said to be operated in saturation region and in this region, base current Ib does not correspond to Ic,**

<u>Cut off Region</u>

- **A small amount of collector current Ic flows even when Ib=0, This is called emitter leakage current.**

iii) Common Collector Configuration:



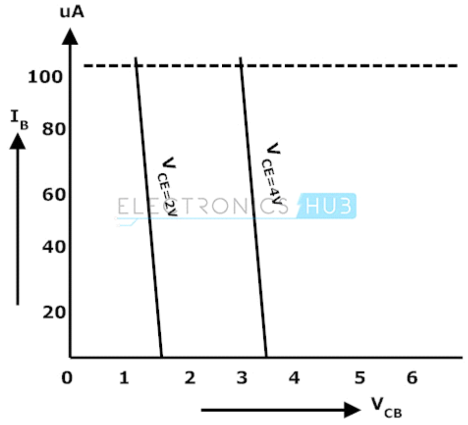
- **Input is applied between base and collector while output is applied between emitter and collector.**
- **The collector forms the terminal common to both the input and output.**
  GAIN is a term used to describe the amplification capabilities of an amplifier. It is basically a ratio of output to input. The current gain for the three transistor configurations (CB, CE, and CC) are ALPHA(a), BETA (b), and GAMMA (g), respectively.

$$\alpha = \frac{\Delta I_C}{\Delta I_E}$$

$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

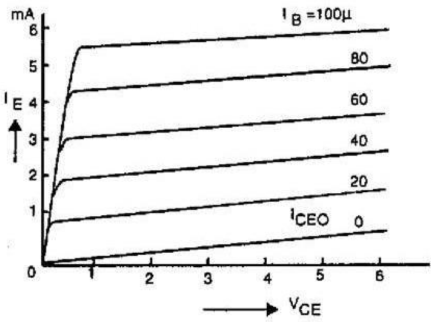
$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

i) Input Characteristics



- **To determine the i/p characteristics Vce is kept at a suitable fixed value.**
- **The base collector voltage Vbc is increased in equal steps and the corresponding increase in Ib is noted.**
- **This is repeated for different fixed values of Vce.**

ii) Output Characteristics



Current components in a Transistor

- **As a result of biasing the active region current flows to drift and diffusion in various parts of transition.**
- **Due to forward bias across input junction, there across three phenomena.**

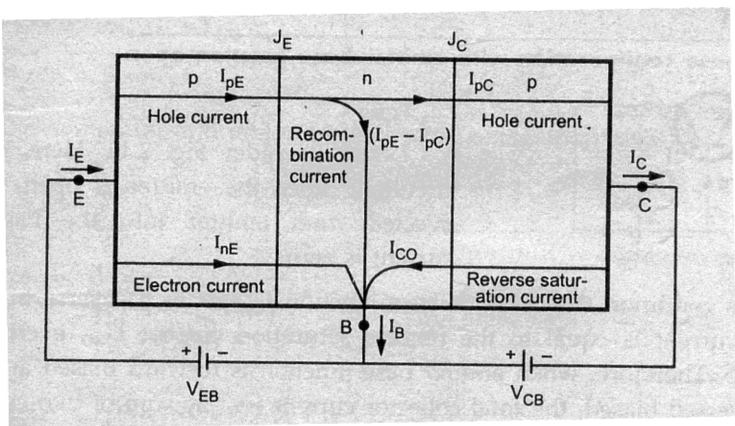
  a) The generation and Recombination of electrons and holes

  Let,

  n -> Electron concentration
  P -> Hole concentration
  Tn -> Life time of electron
  Tp -> Life time of Holes
  no -> Equilibrium density of electrons
  po -> Equilibrium density of Holes

Transistor Current Components

- **In the figure we show the various components which flow across the forward-based emitter junction and the reverse-biased collector junction.**
- **The emitter current I_E consists of hole current I_{pE} (holes crossing from the emitter into base) and electron current I_{nE} (electron crossing from base into the emitter).**
- **The ratio of hole to electron currents, I_{pE} / I_{nE}, crossing the emitter junction is proportional to the ratio of the conductivity of the p material to that of the n material.**
- **In the commercial transistor the doping of the emitter is made much larger than the doping of the base.**
- **This future ensures (in a p-n-p transistor) that the emitter current consists almost entirely of the holes.**
- **Such a situation is desired since the current which results from electrons crossing the emitter junction from base to emitter does not contribute carriers which can reach the collector.**
- **Not all the holes crossing the emitter junction J_E reach the collector junction J_c because some of them combine with the electrons in the n – type base.**
- **If I_{pc} is the hole current at J_c, there must be a bulk recombination current I_{pE} - I_{pC} leaving the base (actually, electrons enter the base region through the base lead to supply those charges which have been lost by recombination with the holes injected into the base across $J_{E)}$.**



- **If the emitter were open-circuited so that I_E = 0, then I_{pC} would be zero.**
- **Under these circumstances, the base and collector would act as a**

reverse-biased diode, and the collector current I_c would equal the reverse saturation current I_{CO}. If $I_E \neq 0$, then

- From figure, we note that

$$I_C = I_{CO} - I_{pC}$$

- For a p-n-p transistor, I_{co} consists of holes moving across J_c from left to right (base to collector) and electrons crossing J_c in the opposite direction.

- Since the assumed reference direction for I_{co} in figure is from right to left, then for a p-n-p transistor, I_{co} is negative. For an n-p-n transistor, I_{co} is positive.

Emitter Efficiency:- (γ)

- The emitter, or injection, efficiency γ is defined as γ

$$\equiv \frac{\text{Current of injected carriers at } J_E}{\text{Total emitter current}}$$

Transport Factor:- (β^*)

- The transport factor β^* is defined as

$$\beta^* \equiv \frac{\text{injected carrier current reaching } J_c}{\text{injected carrier current at } J_E}$$

In the case of a p-n-p transistor we have

$$\beta^* = I_{pC} / I_{pE}$$

Large – signal current Gain:- (α)

- We define the ratio of the negative of the collector-current increment to the emitter-current change from zero (cutoff) to I_E as the large-signal currant gain of a common-base transistor, or

$$\alpha = - I_c - I_{co} / I_E$$

- since I_c and I_E have opposite signs, then α, as defined, is always positive Typical numerical values of α lie in the range of 0.90 to 0.995.

$$\alpha = I_{pC} / I_E$$

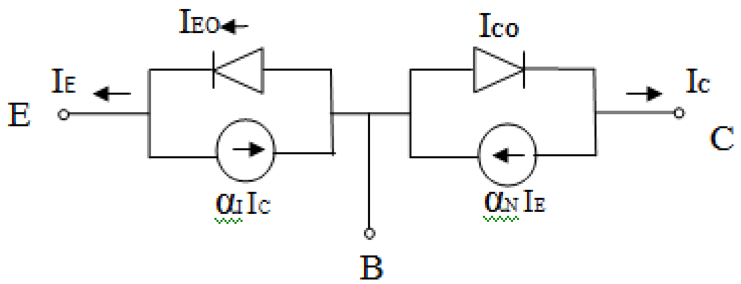
$$= I_{pC} / I_{pE} \,.\, I_{pE} / I_E \ \alpha$$

$$= \beta^* \gamma$$

$$I_C = - \alpha I_E + I_{co}$$

$$I_c = - \alpha I_E + I_{co} (1- e^{Vc} / {}^{Vr})$$

Description of Ebers-moll model



- **The current equation derived above is interpreted in terms of a model shown in the figure.**
- **This model of transistor is known as Eber Moll model of transistor. From the diagram applying Kirchhoff's current law at the collector node, we get**

$$I_C = -\alpha_N * I_E + I_{CO} * (1 - e^{V}{}_{CB}/V_t)$$

- **Where α_N is the current gain of common base transistor mentioned above in normal mode of operation, V_{BC} is the base to collector voltage, I_{co} is the reverse saturation current of base collector junction.**
- **Similarly at emitter and base node by applying Kirchhoff's current law**

$$I_E = -\alpha_I * I_C + I_{EO}(1 - e^{V}{}_{BE}/V_t),\ I_E + I_B + I_C = 0$$

- **Where α_I is the inverted current gain of common base transistor with roles of collector and emitter interchanged, V_{BE} is the base to Emitter voltage, I_{co} is** the reverse saturation current of base Emitter junction. αI and αI are related through the reverse saturation currents of the diode as

$$\alpha_I * I_{CO} = \alpha_N * I_{EO}$$

- The above equations are derived based on the assumption of low level minority carrier injection (the hole concentration injected into the base is very much less compared to the intrinsic electron concentration in base), in such a case emitter or collector current is mainly dominated by diffusion currents, drift current is negligible compared to drift currents.
- The Base to emitter voltage and base to collector voltage in terms of currents can be derived as follows

$$I_E = -\alpha_I * I_C + I_{EO}(1 - e^{V_{BE}/V_t}),\ I_C = -\alpha_N * I_E + I_{CO} *(1 - e^{V_{CB}/V_t})$$

$$I_E + \alpha_I * I_C = I_{EO}(1 - e^{V_{BE}/V_t}),\ I_C + \alpha_N * I_E = I_{CO} *(1 - e^{V_{CB}/V_t})$$

$$(I_E + \alpha_I * I_C)/I_{EO} = (1 - e^{V_{BE}/V_t}),\ (I_C + \alpha_N * I_E)/I_{CO} = (1 - e^{V_{CB}/V_t})$$

$$e^{V_{BE}/V_t} = 1 - ((I_E + \alpha_I * I_C)/I_{EO}),\ e^{V_{CB}/V_t} = 1 - ((I_C + \alpha_N * I_E)/I_{CO})$$

- Applying anti log on both sides we get

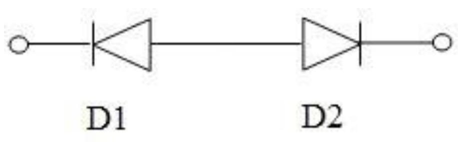
$$V_{BE} = V_t * \ln(1 - ((I_E + \alpha_I * I_C)/I_{EO})),\ V_{CB} = V_t * \ln(1 - ((I_C + \alpha_N * I_E)/I_{CO}))$$

- For example in cutoff region I_E=0 amps and $I_C = I_{CO}$ then the base to emitter voltage is

$$V_{BE} = V_t * \ln(1 - (\alpha_I * I_{CO})/I_{EO})$$

$$V_{BE,\ cut\ off} = V_t * \ln(1 - \alpha_N)$$

- Consider two diodes connected back to back in the configuration shown below



- It is obvious that if one junction is forward biased then other junction will be reverse biased
- consider for example diode D1 is forward biased and diode D2 is reverse biased much like a NPN transistor in active region according to the junction voltages only current order of reverse saturation current flows through the series junctions.
- This can be explained as follows: the reverse biased diode D2 at most will

allow only currents order of reverse saturation currents.

- **Since D1 and D2 are in series same current should flow through both of them then only currents order of reverse saturation currents flow through their junctions.**
- **It is obvious that this is not the case with the transistor in active region (Because of the internal design of transistor).**
- **The forward current entering the base is sweeped across into collector by the electric field generated by the reverse bias voltage applied across the base collector junction.**

Base width modulation:-

As the applied base-collector voltage (VBC) varies, the base-collector depletion region varies in size. This variation causes the gain of the device to change, since the gain is related to the width of the effective base region. This effect is often called the "Early Effect".

SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND COMMMUNICATION ENGINEERING

UNIT - III

ELECTRONIC DEVICES – SECA1101

UNIT-III

JFETs – Drain and Transfer characteristics, -Current Equations-Pinch off voltage and its significance-

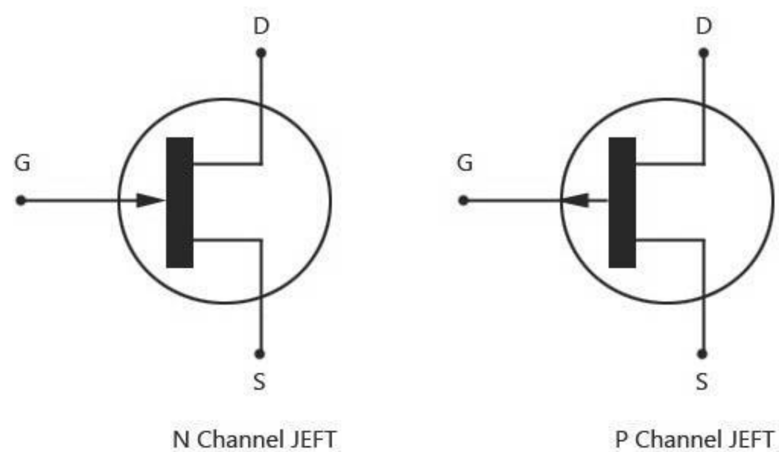
MOSFET Characteristics-

Threshold voltage -Channel length modulation, D-MOSFET, E-MOSFET- Characteristics –

Comparison of MOSFET with JFET, DUAL GATE MOSFET.

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 p-n 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).

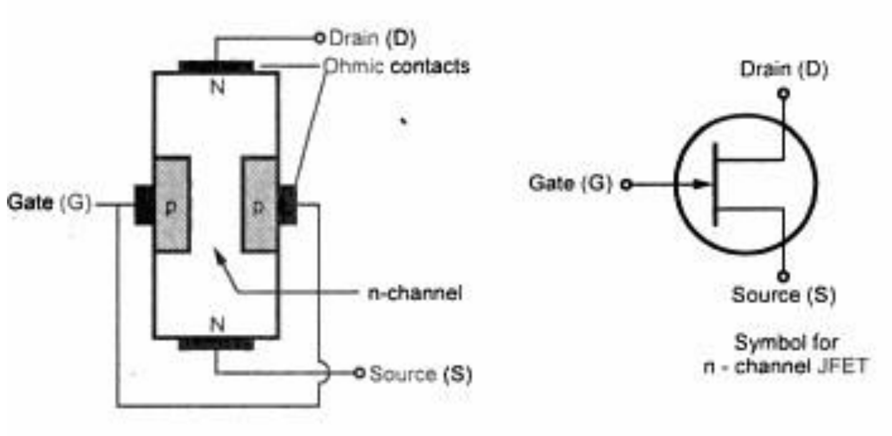


JFET-N-Channel and P-channel Schematic Symbol

Construction

n-channel JFET

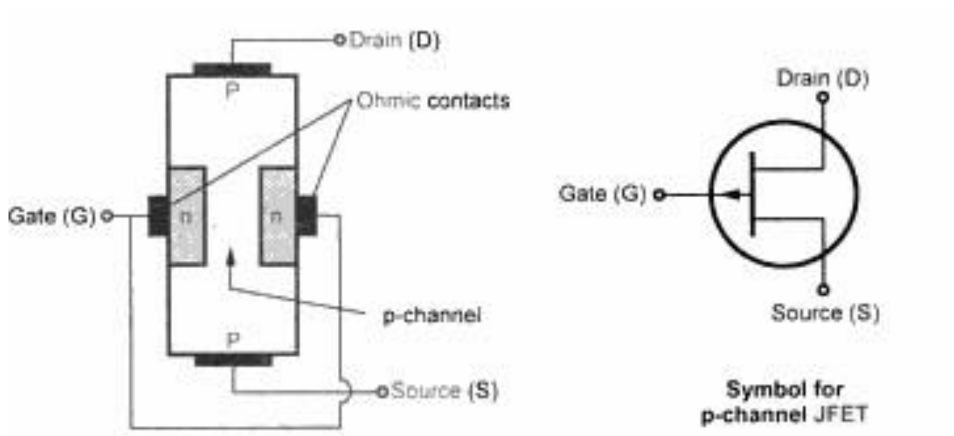
The figure shows construction and symbol of n-channel JFET. A small bar of extrinsic semiconductor material, n type is taken and its two ends, two ohmic contacts are made which is the drain and source terminals of FET. Heavily doped electrodes of p type material form p-n junctions on each side of the 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 in the figure.

p-channel JFET

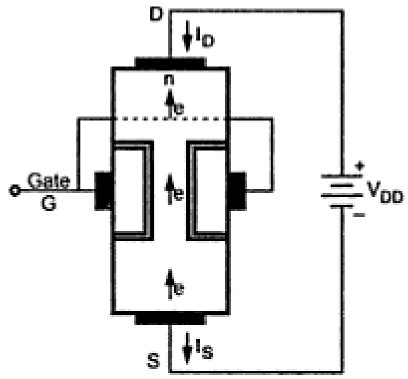
The device could be made of p type bar with two n type gates as shown in the figure. This will be p-channel JFET. The principle of working of n-channel JFET and p- channel JFET are similar. The only difference being that in n-channel JFET the current is carried by electrons while in p-channel JFET, it is carried by holes.



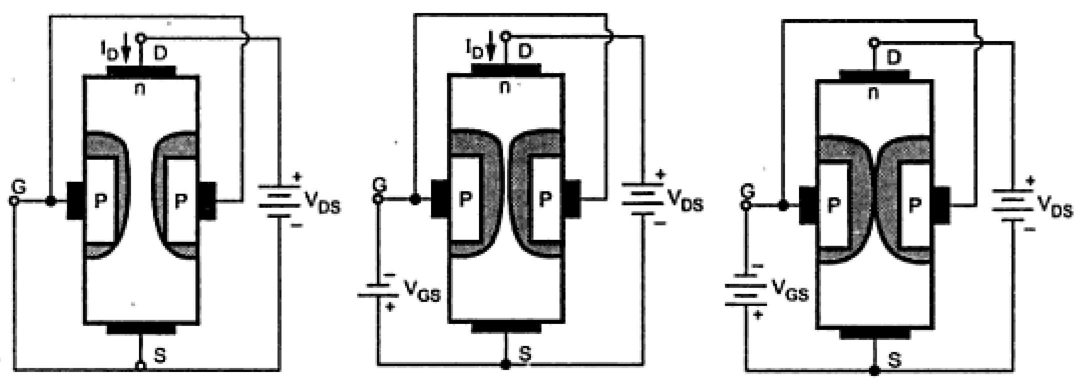
Operation

In JFET, the p-n junction between gate and source is always kept in reverse biased conditions. Since the current in a reverse biased p-n junction is extremely small, practically zero. The gate current in JFET is often neglected and assumed to be zero.

Let us consider the circuit in the figure, voltage V_{DD} is applied between drain and source. Gate terminal is kept open. The bar is of n-type material. Due to the polarities of applied voltage as shown in the fig, the majority carriers i.e. the electrons start flowing from the source to the drain. The flow of electrons makes the drain current, $I_{D.}$



The majority carriers move from source to drain through the space between the gate regions. The space is commonly known as **channel.** The width of this channel can be controlled by varying the gate voltage. To see the effect of gate voltage on channel- width and on drain current $I_{D,}$ consider the diagram below.



(a) No bias voltage on gates

(b) Small negative gate source bias

(c) Large negative gate source bias

The figure (a) shows that an n-channel JFET with the gate directly connected to the source terminal. When drain voltage V_{DS} is applied, a drain current I_D flows in the direction shown. Since the n-material is resistive, the drain current causes a voltage drop along the channel. This voltage drop reverse biases the pn junctions, and causes the depletion regions to penetrate into the channel. Since gate is heavily doped and the channel is lightly doped the width of the depletion region will mainly be spread in the channel as shown in fig (a). This penetration depends on the reverse bias voltage. From the figure, it can be observed that depletion region width is more at the drain side as compared to source side because near the junction, voltage at drain side is more than the voltage at the source side. This shows that reverse bias is not uniform near the junction as it gradually increases from source side to drain side.

The depletion region does not contain charge carriers. The space between two depletion regions is available for conducting portion of the channel. When reverse bias voltage is applied externally to the gate, the reverse bias will increase and hence increase the penetration of the depletion region which reduces the width of the conducting portion of the channel. When the width of the conducting portion of the channel reduces, the no. of electrons flowing from source to drain reduces and hence the current flowing from drain to source reduces.

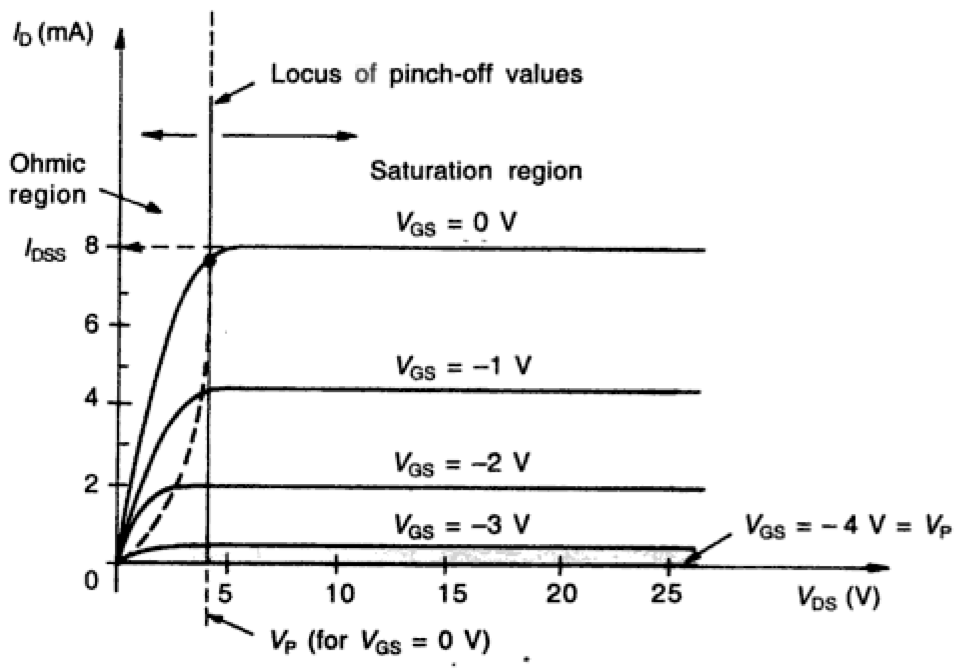
When the external reverse bias voltage at the gate is increased as shown in fig (b) & (c) the depletion regions will increase more and at a particular stage the width of the depletion region will be equal to the original width of the depletion regions will increase more and more, and stage will come when the width of the depletion regions will be equal to the original width of the channel, leaving zero width for conducting portion of the channel, as shown in the fig (c). This will prevent any current flow from drain to source and this will cut off the drain current. The gate to source voltage that produces cutoff is known as cutoff voltage ($V_{GS\ (OFF)}$).

When the gate is shorted to source, there is minimum reverse bias between gate and source p-n junction, making depletion region width minimum and conducting channel width maximum. In this case a maximum drain current flow which is designated by IDSS and this is the possible drain current in JFET. It is clear that the gate to source voltage controls the current flowing through the channel and hence FET is also called **voltage controlled current source.**

Characteristics

Drain (or) current voltage characteristics of JFET

The current voltage characteristics of an n-channel JFET is shown in the figure. The drain current (I_D) is plotted with V_{DS} for different values of V_{GS}. This characteristic is also known as drain characteristics of JFET. From the fig, we see that as the voltage increased from 0 to a few volts, the current increases as determined by ohm's law. The straight nature of the curve at low values for V_{DS} reveals that for this region the resistance is essentially constant for a fixed valued of V_{GS}. But the slope of the I_D - V_{DS} curve near the origin is a function of the gate voltage. This region of operation is known as the linear region or ohmic region. As V_{DS} increases and approaches a value V_P (referred to as pinch – off voltage), slope of the curve changes and the channel resistance increases. If V_{DS} increases beyond pinch-off value, characteristics curve becomes more horizontal and I_D maintains a saturation level. For V_{GS} = 0v , the saturated value of I_D is designated as I_{DSS} , which is the drain – to – source current with source – gate short circuit. Thus, I_{DSS} is the maximum drain current for a JFET, obtained under the conditions V_{GS} = 0V and $V_{DS} > |V_P|$. As the V_{DS} increases beyond V_P, the level of I_D remains essentially the same and this region of the characteristics is known as saturation region. It may also be noted that once $V_{DS} > V_{p,}$ the JFET has the characteristics of a current source. Thus the current – voltage characteristics displayed in fig can be divided into ohmic (linear) and saturation regions with the pinch-off condition as the boundary.



As the negative bias of V_{GS} increases, depletion region forms similar to those to those with V_{GS} = 0 V but at a lower level of $V_{DS.}$ Thus, the result of applying a negative bias to the gate is to reach the saturation level at a lower level of V_{DS}, as shown in the fig. it is seen that V_{GS} = -V_P, the saturation level of I_D is essentially 0mA and the devices have been turned off. The region of the right of the pinch-off locus in figure is normally employed in linear amplifiers. The region to the left of the pinch-off locus is referred to as *voltage controlled resistance region*, where the JFET can be used as voltage- controlled resistor. The channel resistance (R_D) increases with increase of V_{GS} values and empirical relation between the two is given by

$$R_D = \frac{R_0}{[1 - (V_{GS}/V_P)]^2}$$

Where R_0 is the resistance with V_{GS} = 0. For an n-channel JFET with R_0 = 10kΩ at V_{GS} = -2V.

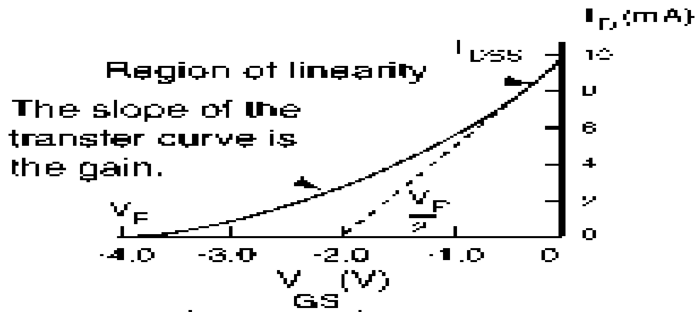
The drain currents suddenly rise in an unbounded manner at very high levels of V_{DS}. The vertical rise in current is an indication that breakdown has occurred and the current through the channel is now limited solely by external circuit. In practical applications, the level of V_{DS} is kept less than the breakdown voltages (V_{DSmax}) that are mentioned in specification sheets of JFET.

Transfer characteristics

The transfer characteristics of JFET is a plot of output (drain) current versus input controlling quantity (gate-source voltage) and is used extensively in JFET amplifiers. In contrast to linear input-output relationship of BJT ($I_C = \beta I_B$), the input-output relationship of JFET is not linear. The relationship between I_D and V_{GS} is defined by Shockley's equation:

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

The squared term on the right-hand side of the equation suggests that the relationship of I_D vs V_{GS} is nonlinear and exponential in nature. The transfer characteristics defined by Shockley's equation are unaffected by the network in which the device is employed. The transfer curve can be obtained using Shockley's equation or from the o/p characteristics.



Transfer curve for a JFET

Expression for pinch off voltage and Drain Current

For the transfer characteristics, V_{DS} is maintained constant at a suitable value greater than the pinch off voltage V_P. The gate voltage V_{GS} is decreased from zero till I_D is reduced to zero. The transfer characteristics I_D versus V_{GS} are shown in figure.

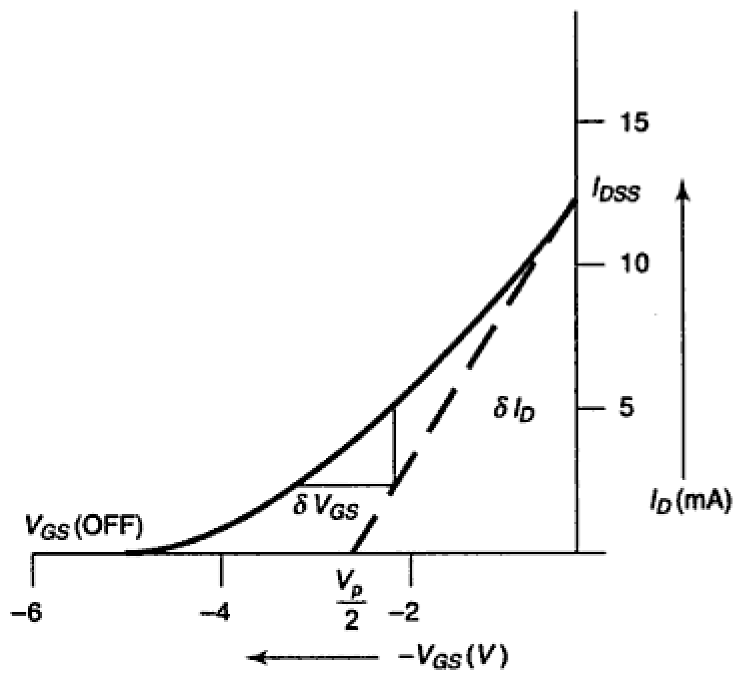


Fig. 7.5 Transfer characteristics of JFET

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 \qquad (1)$$

Where I_{DS} is the saturation drain current, I_{DSS} is the value of I_{DS} when $V_{GS}=0$ and V_P is the pinch off voltage

Differentiating eqn (1) with respect to VGS we obtain the expression of gm

$$g_m = -2\, I_{DSS}/V_P(1 - V_{GS}/V_P) \qquad (2)$$

From eqn (1)

$$(1-V_{GS}/VP) = (I_{DS}/I_{DSS})^{1/2} \qquad (3)$$

Suppose $g_m=g_{m0}$ when $v_{GS}=0$

$$g_{mo} = -2I_{DSS}/V_P \qquad (4)$$

Therefore from eqn (2) and (4)

$$\mathbf{g_m = g_{m0}(1 - V_{GS}/V_P)}$$

MOSFET

MOSFET stands for metal oxide semiconductor field effect transistor. It is capable of voltage gain and signal power gain. The MOSFET is the core of integrated circuit designed as thousands of these can be fabricated in a single chip because of its very small size. Every modern electronic system consists of VLST technology and without MOSFET, large scale integration is impossible.

It is a four terminals device. The drain and source terminals are connected to the heavily doped regions. The gate terminal is connected top on the oxide layer and the substrate or body terminal is connected to the intrinsic semiconductor.

MOSFET has four terminals which is already stated above, they are gate, source drain and substrate or body. MOS capacity present in the device is the main part. The conduction and valance bands are position relative to the Fermi level at the surface is a function of MOS capacitor voltage. The metal of the gate terminal and the sc 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.

Two basic types of MOSFET are n channel and p channel MOSFETs. In n channel MOSFET is current is due to the flow of electrons in inversion layer and in p channel current is due to the flow of holes. Another type of characteristics of clarification can be made of those are enhancement type and depletion type MOSFETs. In enhancement mode, these are normally off and turned on by applying gate voltage. The opposite phenomenon happens in depletion type MOSFETs.

Working Principle of MOSFET

The working principle of MOSFET depends up on the MOS capacitor. The MOS capacitor is the main part. The semiconductor surface at below the oxide layer and between the drain and source terminal can be inverted from p-type to n-type by applying a positive or negative gate voltages respectively. When we apply positive gate voltage the holes present beneath the oxide layer experience repulsive force and the holes are pushed downward with the substrate. The depletion region is populated by the bound negative charges, which are associated with the acceptor atoms. The positive voltage also attracts electrons from the n+ source and drain regions in to the channel. The electron reach channel is formed. Now, if a voltage is applied between the source and the drain, current flows freely between the source and drain gate voltage controls the electrons concentration the channel. Instead of positive if apply negative voltage a hole channel will be formed beneath the oxide layer.

Now, the controlling of source to gate voltage is responsible for the conduction of current between source and the drain. If the gate voltage exceeds a given value, called the three voltage only then the conduction begins.

The current equation of MOSFET in triode region is –

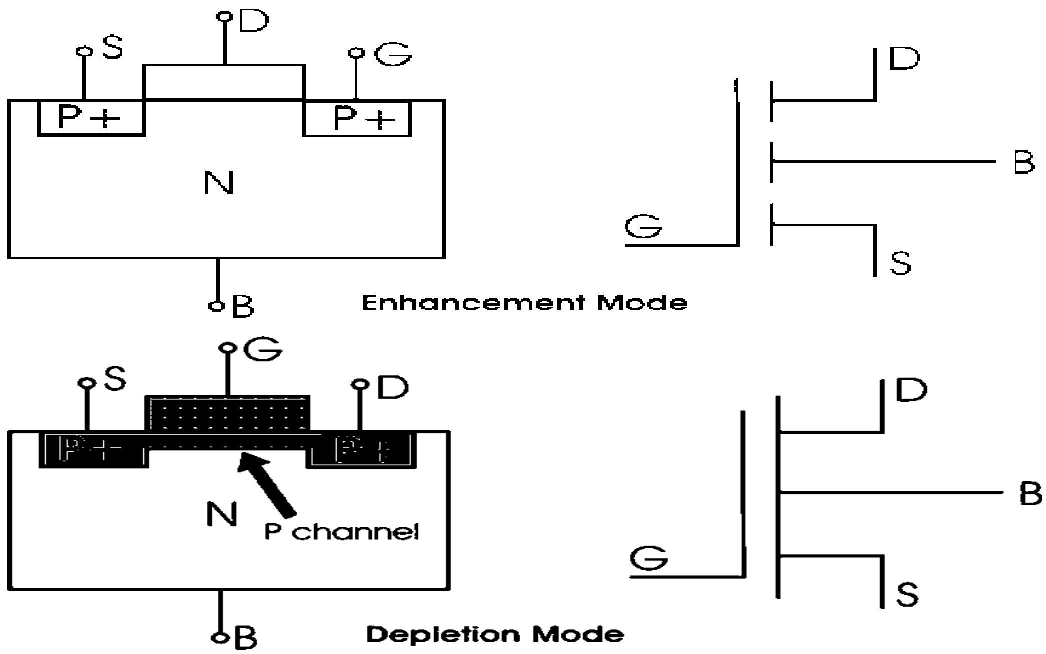
$$I_D = u_n C_{ox} \frac{W}{2}[(V_{GS} - V_{TH})V_{DS} - \frac{1}{2}V_{DS}^2]$$

Where, un = Mobility of the electrons Cox = Capacitance of the oxide layer W = Width of the gate area L = Length of the channel VGS = Gate to Source voltage VTH = Threshold voltage VDS = Drain to Source voltage.

P-Channel MOSFET

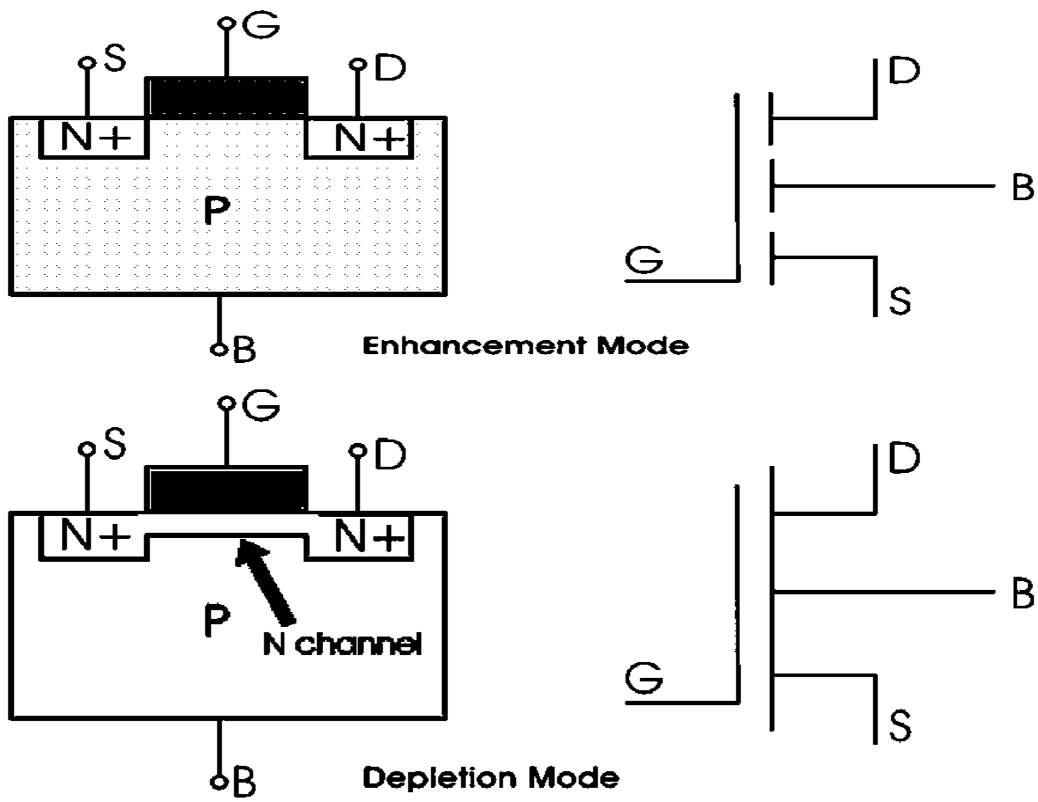
MOSFET which has p - channel region between source any gate is known as p - channel MOSFET. It is a four terminal devices, the terminals are gate, drain, source and substrate or body. The drain and source are heavily doped p+ region and the substrate is in n-type. The current flows due to the flow of positively charged holes that’s why it is known as p-channel MOSFET. When we apply negative gate voltage, the electrons present beneath the oxide layer, experiences repulsive force and they are pushed downward in to the substrate, the depletion region is populated by the bound positive charges which are associated with the donor atoms. The negative gate voltage also attracts holes from p+ source and drain region in to the channel region. Thus hole which channel is formed now if a voltage between the source and the drain is applied current flows. The gate voltage controls the hole concentration of the channel. The diagram of p- channel enhancement and depletion MOSFET are given below.

N-Channel MOSFET



MOSFET having n-channel region between source and drain is known as n-channel MOSFET . It is a four terminal device, the terminals are gate, drain and source and substrate or body. The drain and source are heavily doped n+ region and the substrate is p-type. The current flows due to flow of the negatively charged electrons, that’s why it is known as n- channel MOSFET. When we apply the positive gate voltage the holes present beneath the oxide layer experiences repulsive force and the holes are pushed downwards in to the bound negative charges which are associated with the acceptor atoms. The positive gate voltage also attracts electrons from n+ source and drain region in to the channel thus an electron reach channel is formed, now if a voltage is applied between the source and drain.

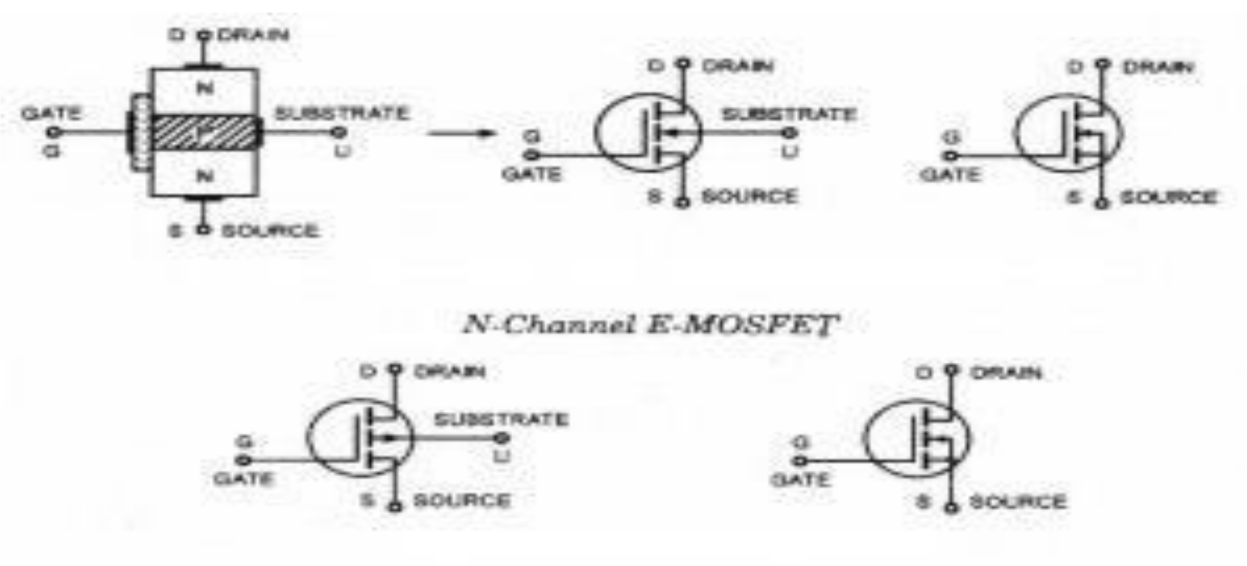
The gate voltage controls the electron concentration in the channel n-channel MOSFET is preferred over p-channel MOSFET as the mobility of electrons are higher than holes. The diagrams of enhancements mode and depletion mode are given below.



Enhancement and Depletion Mode MOSFET

EMOSFET

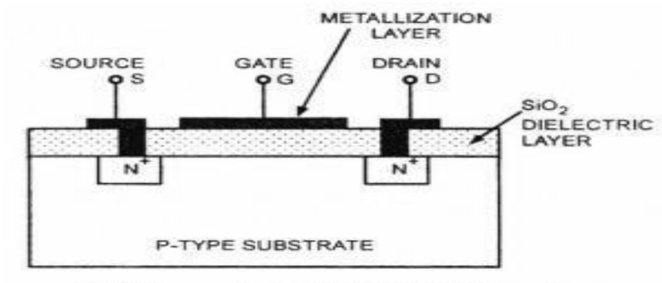
Symbol



N-Channel E-MOSFET

P-Channel E-MOSFET
Schematic Symbols For E-MOSFETs

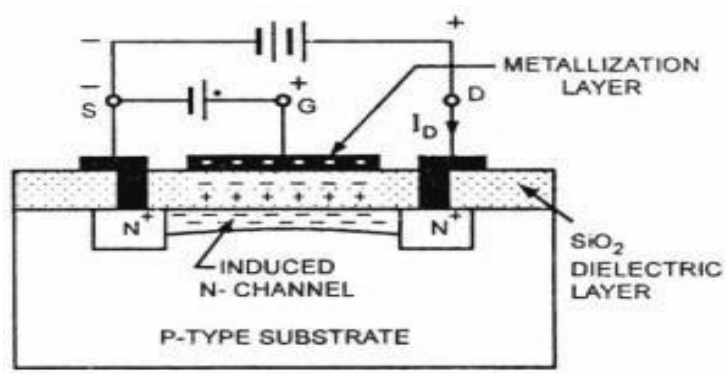
Construction



N-Channel E-MOSFET Structure

Figure shows the construction of an N-channel E-MOSFET. The main difference between the construction of DE-MOSFET and that of E-MOSFET, as we see from the figures given below the E-MOSFET substrate extends all the way to the silicon dioxide (SiO_2) and no channels are doped between the source and the drain. Channels are electrically induced in these MOSFETs, when a positive gate-source voltage V_{GS} is applied to it.

Operation



Operation of N-Channel E-MOSFET

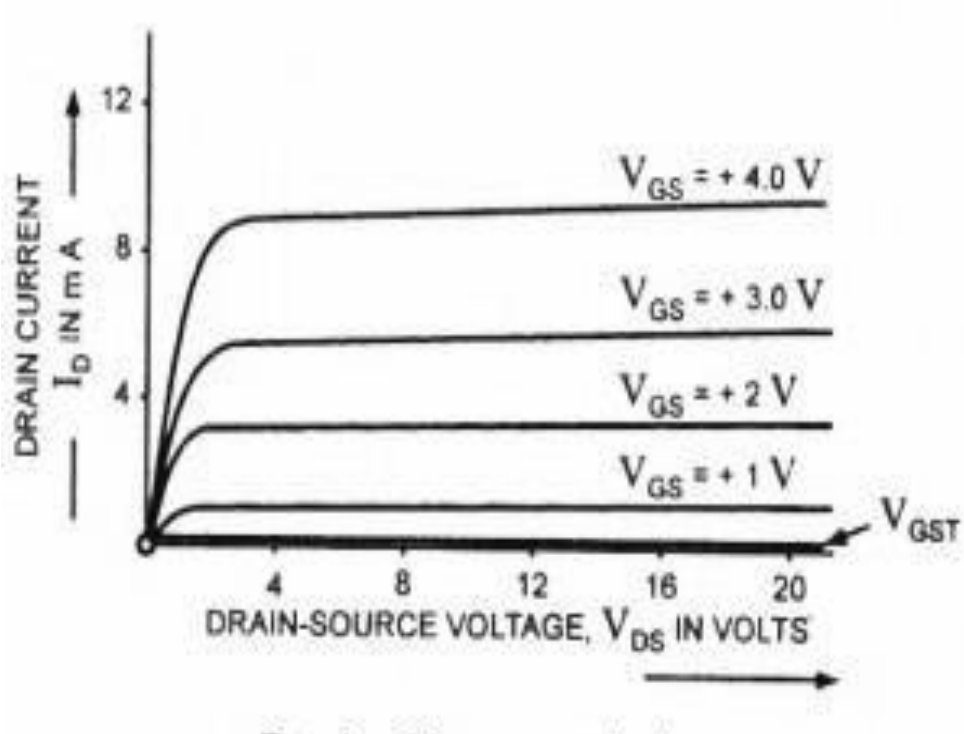
As its name indicates, this MOSFET operates only in the enhancement mode and has no depletion mode. It operates with large positive gate voltage only. It does not conduct when the gate-source voltage VGS = 0. This is the reason that it is called normally-off MOSFET. In these MOSFET's drain current ID 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, reverses 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 cannot 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 starts 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 V_{GS} that is required to form the inversion layer (N-type) is termed the gate-to-source threshold voltage V_{GST}. For V_{GS} below V_{GST}, the drain current $I_D = 0$. But for V_{GS} exceeding V_{GST} an N-type inversion layer connects the source to drain and the drain current I_D is large. Depending upon the device being used, V_{GST} may 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 $V_{GS} = 0$, whereas the enhancement-mode devices are normally OFF when $V_{GS} = 0$.
Characteristics
Drain Characteristics
Drain characteristics of an N-channel E-MOSFET are shown in figure. The lowest curve is the V_{GST} curve. When V_{GS} is lesser than V_{GST}, I_D is approximately zero. When V_{GS} is greater than V_{GST}, the device turns- on and the drain current I_D is controlled by

the gate voltage. The characteristic curves have almost vertical and almost horizontal parts.



Drain Characteristics

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.

Transfer Characteristics

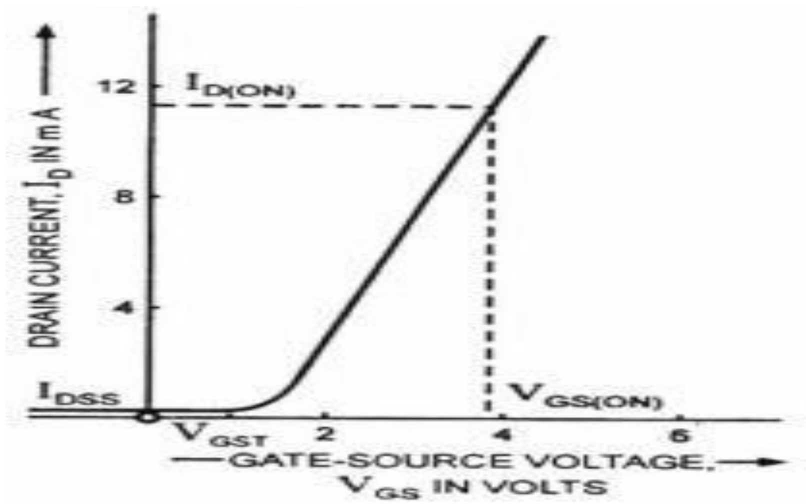
Figure shows a typical transconductance curve. The current IDSS at VGS <=0 is very small, being of the order of a few nano-amperes. When the V_{GS} is made positive, the drain current I_D increases slowly at first, and then much more rapidly with an increase in V_{GS}. The manufacturer sometimes indicates the *gate-source threshold voltage* V_{GST} at which the drain current I_D attains some defined small value, say 10 u A. A current I_D (0N, corresponding approximately to the maximum value given on the drain characteristics and the values of V_{GS} required to give this current $V_{Gs\ QN}$ are also usually given on the manufacturers data sheet.

The equation for the transfer characteristic does not obey equation. However it follows a similar "square law type" of relationship. The equation for the transfer characteristic of E-MOSFETs is given as:

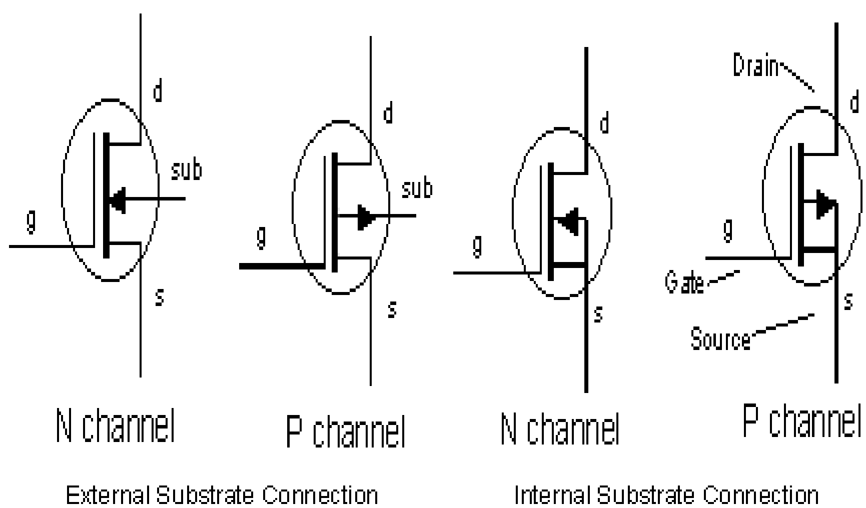
$$I_D=K(V_{GS}-V_{GST})^2$$

Depletion Mode MOSFET

Symbol



Transfer Characteristic



Construction

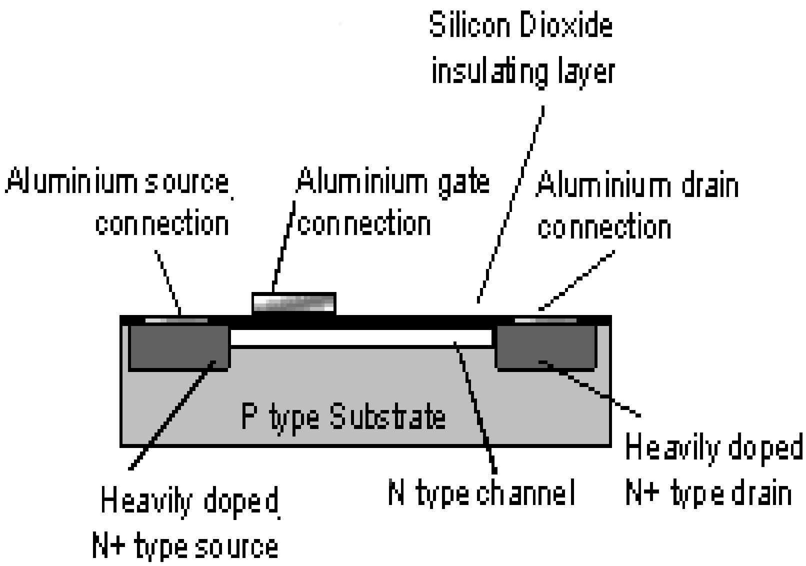


Fig 5.1 Depletion Mode N Channel MOSFET

The depletion mode MOSFET shown as a N channel device (P channel is also available) in Fig 5.1 is more usually made as a discrete component, i.e. a single transistor rather than IC form. In this device a thin layer of N type silicon is deposited just below the gate−insulating layer, and forms a conducting channel between source and drain.

Therefore when the gate source voltage V_{GS} is zero, current (in the form of free electrons) can flow between source and drain. Note that the gate is totally insulated from the channel by the layer of silicon dioxide. Now that a conducting channel is present the gate does not need to cover the full width between source and drain. Because the gate is totally insulated from the rest of the transistor this device, like other IGFETs, has a very high input resistance.

Operation

In the N channel device, shown in Fig. 5.2 the gate is made negative with respect to the source, which has the effect of creating a depletion area, free from charge carriers, beneath the gate. This restricts the depth of the conducting channel, so increasing channel resistance and reducing current flow through the device. Depletion mode MOSFETS are also available in which the gate extends the full width of the channel (from source to drain). In this case it is also possible to operate the transistor in enhancement mode. This is done by making the gate positive instead of negative.

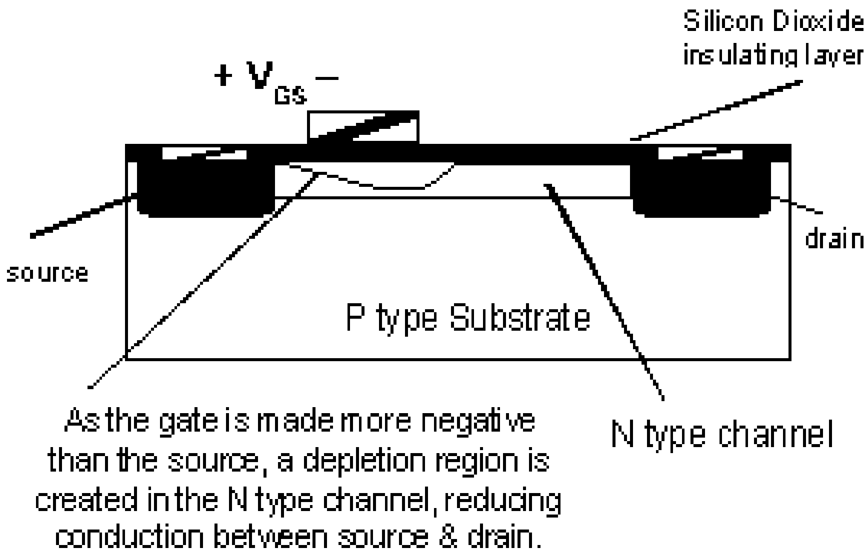
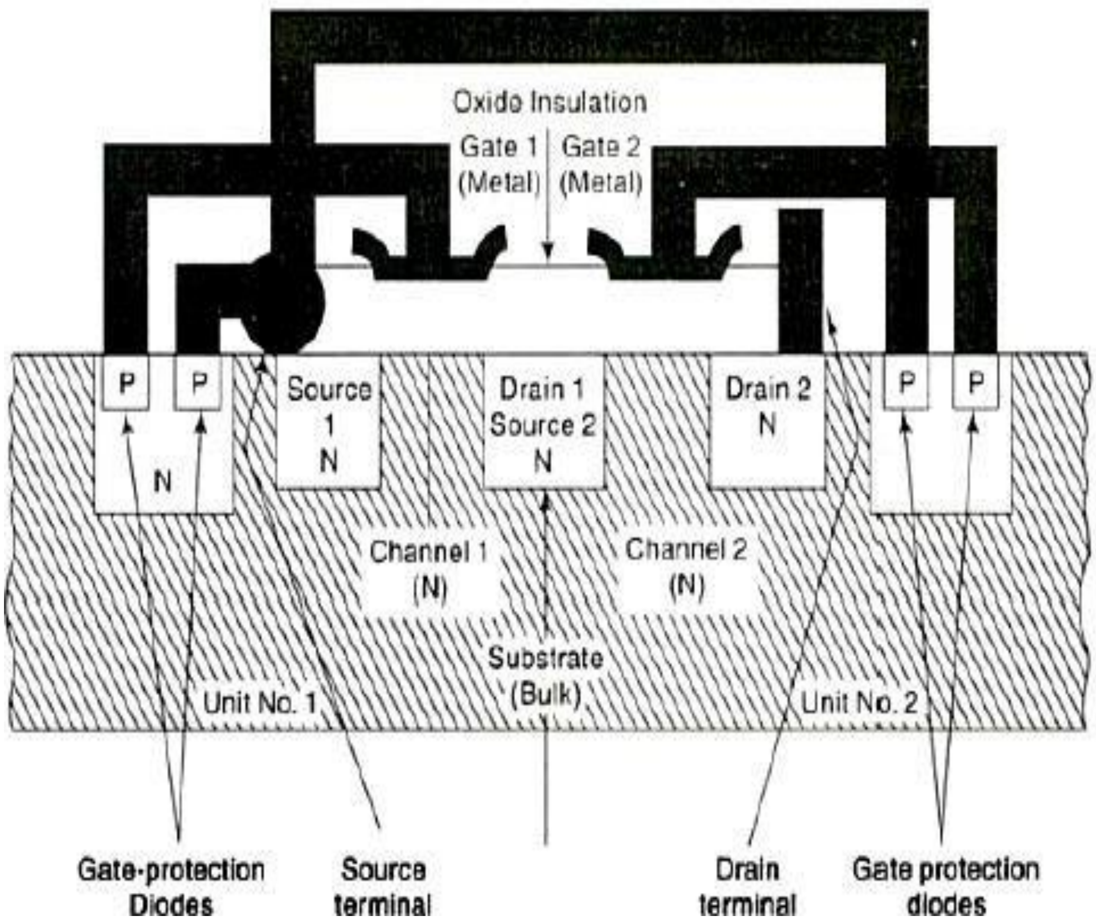


Fig. 5.2 Operation of a Depletion Mode MOSFET

The positive voltage on the gate attracts more free electrons into the conducing channel, while at the same time repelling holes down into the P type substrate. The more positive the gate potential, the deeper, and lower resistance is the channel. Increasing positive bias therefore increases current flow. This useful depletion/enhancement version has the disadvantage that, as the gate area is increased, the gate capacitance is also larger than true depletion types. This can present difficulties at higher frequencies.

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 sorce 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 V_{DS} is small , the drain to source resistance rd can be controlled by the bias voltage V_{GS} . The FET is useful as a voltage variable resistor (VVR) or voltage dependent resistor (VDR) .

In JFET , the drain to source conductance $g_d = I_D/V_{DS}$ for small values of V_{DS} , which may also be expressed as

$$g_d = g_{do}\,[1-(V_{GS}/V_P)^{1/2}]$$

where g_{do} is the value of drain conductance when the bias voltage V_{GS} is zero. The variation of the r_d with V_{GS} can be closely approximated by the empirical expression ,

$$r_d = r_o/(1-KV_{GS})$$

Where r_o=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.

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DEPARTMENT OF ELECTRONICS AND COMMMUNICATION ENGINEERING

UNIT - IV
ELECTRONIC DEVICES – SECA1101

UNIT IV SPECIAL SEMICONDUCTOR DEVICES .

SCR- UJT- DIAC- TRIAC - SCHOTTY BARRIER DIODE-VARACTOR DIODE - PIN DIODE - TUNNEL DIODE - GUNN DIODE – LASER DIODE-OPERATION, CHARACTERISTICS AND APPLICATIONS

In the recent years, such semiconductor devices have been developed which can exercise fine control over the flow of large blocks of power in a system. Such devices act as controlled switches and can perform the duties of controlled rectification, inversion and regulation of power in a load.

The important semiconductor switching devices are :
(i) Silicon controlled rectifier (SCR)
(ii) Triac
(iii) Diac
(iv) Unijunction transistor (UJT)

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.

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 w.r.t. cathode and gate at small positive potential w.r.t. 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.

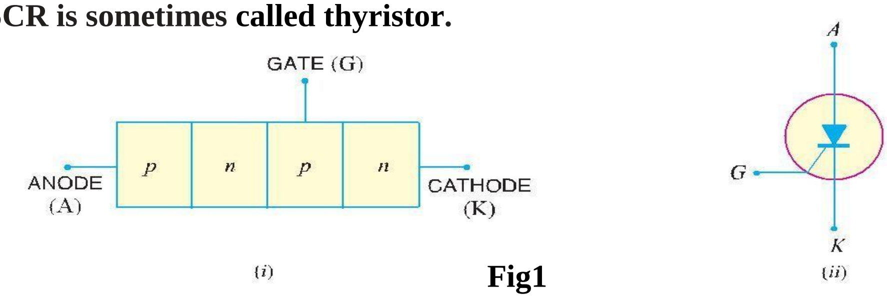


Fig1

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:

(i) When gate is open. Fig.2 shows the SCR circuit with gate open i.e. no voltage appliedto 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 is cut off. 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 Breakover voltage.

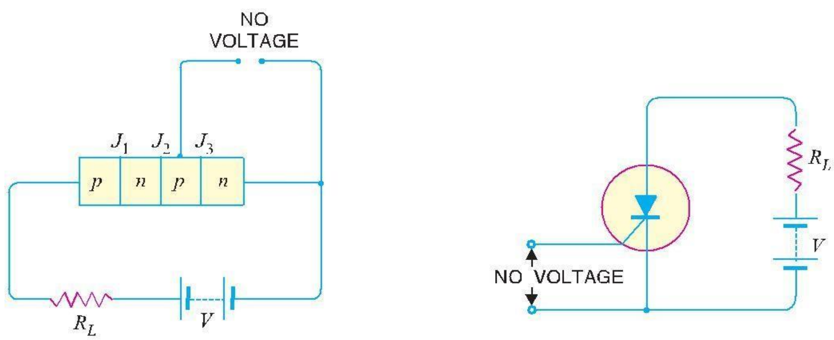


Fig 2

(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 Fig. 20.3. Now junction J3 is forward biased and junction J2 is reverse biased. The electrons from n-type material start mov- ing 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.

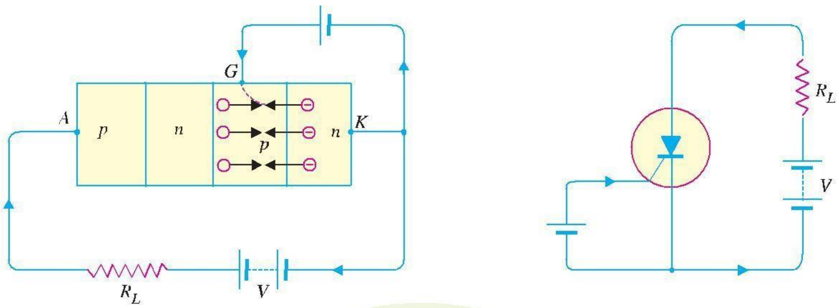


Fig.3

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 :

(i) 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.

(ii) 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.

(iii) 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.

(iv) To open the SCR (i.e. to make it non-conducting), reduce the supply voltage to zero.

The V-I characteristics of the SCR reveal that the SCR can be operated in three modes There are three modes of operation for an SCR depending upon the biasing given to it:

1. **Forward blocking mode (off state)**
2. **Forward conduction mode (on state)**
3. **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 breakover 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 milliamperes 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 voltahe should never cross the breakdown voltage

V-I Characteristics of SCR

It is the curve between anode-cathode voltage (V) and anode current (I)of an SCR at constant gate current. Fig. 4 shows the V-I characteristics of a typical SCR.

Forward characteristics.

When anode is positive w.r.t. cathode, the curve between V and I is called the forward characteristic. In Fig. 4, 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.

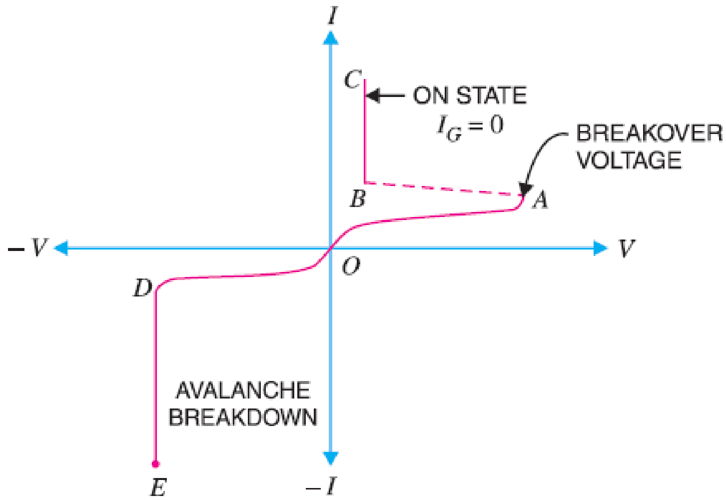


FIG:4 VI CHARACTERISTIC OF SCR

EQUIVALENT CIRCUIT OF SCR

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

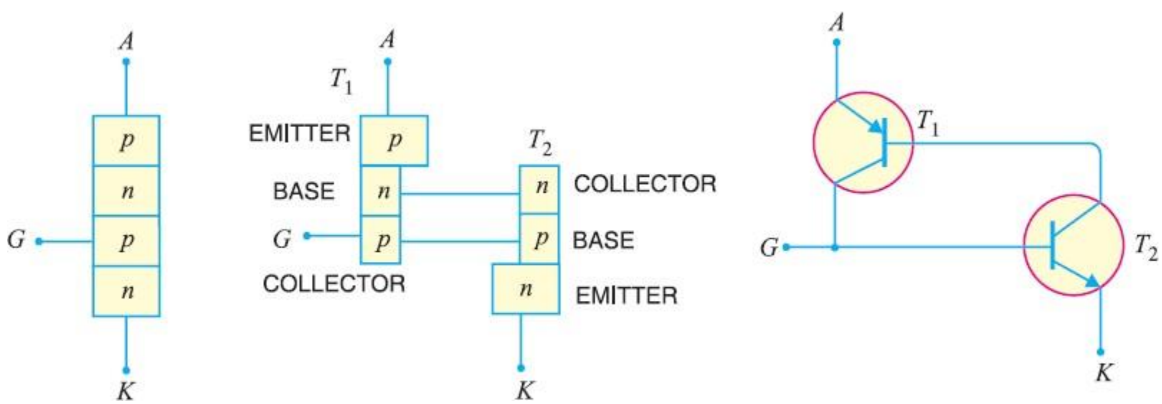


Fig 5

Fig. 5. Thus, the equivalent circuit of *SCR* is composed of *pnp* transistor and *npn* transistorconnected as shown in Fig.5. It is clear that collector of each transistor is coupled to the baseof the other, thereby making a positive feedback loop.

The working of *SCR* can be easily explained from its equivalent circuit. Fig. 6 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 inthe collector of *T*2 and hence that of *T*1. Under such conditions, the *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.

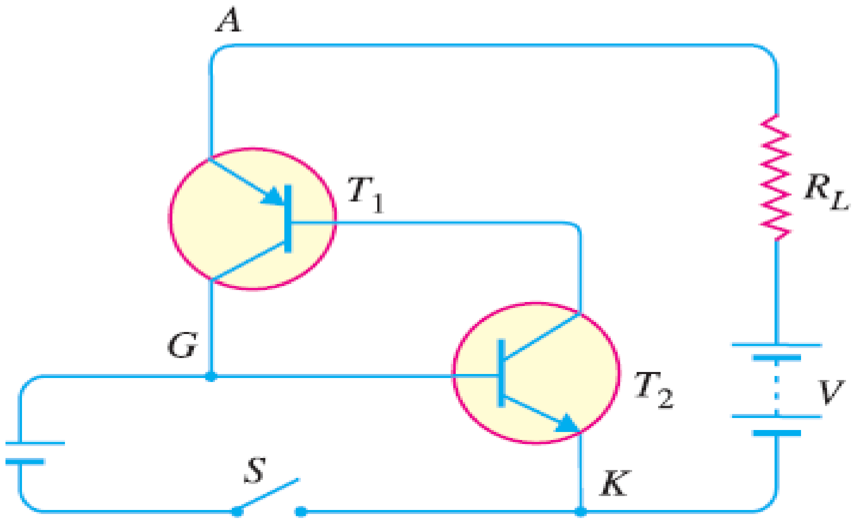


Fig 6

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

silicon controleld rectifiers, 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.

TRIAC

The major drawback of an SCR is that it can conduct current in one direction only. Therefore, an SCR can only control d.c. power or forward biased half-cycles of a.c. in a load. However, in an a.c. system, it is often desirable and necessary to exercise control over both positive and negative halfcycles. For this purpose, a semiconductor device called triac is used

A triac is a three-terminal semiconductor switching device which can control alternating current in a load. Triac is an abbreviation for triode a.c. switch. 'Tri'– indicates that the device has three terminals and 'ac' means that the device controls alternating current or can conduct current in either direction.

The key function of a triac may be understood by referring to the simplified Fig.7(i) . The control circuit of triac can be adjusted to pass the desired portions of positive and negative half cycle of a.c. supply through the load RL. Thus referring to Fig. 7 (ii), the triac passes the positive half-cycle of the supply from θ1 to 180° i.e. the shaded portion of positive half-cycle. Similarly, the shaded portion of negative half-cycle will pass through the load. In this way, the alternating current and hence a.c. power flowing through the load can be controlled

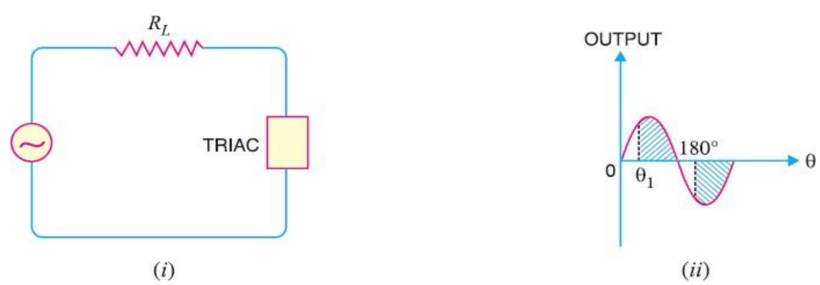
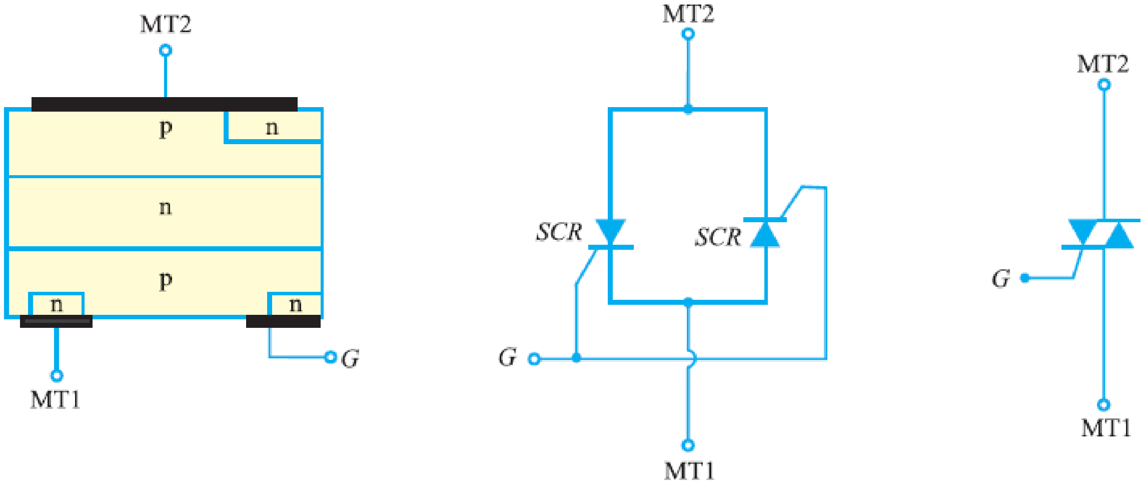


Fig 7

Since a triac can control conduction of both positive and negative half-cycles of a.c. supply, it is sometimes called a bidirectional semi-conductor triode switch. The above action of a triac is certainly not a rectifying action (as in an *SCR) so that the triac makes no mention of rectification in its name

Triac Construction

A triac is a three-terminal, five-layer semiconductor device whose forward and reverse characteristics are indentical to the forward characteristics of the SCR. The three terminals are designated as main terminal MT1, main terminal MT2 and gate G.



(i) (ii) (iii)

Fig 8

Fig. 8 (i) shows the basic structure of a triac. A triac is equivalent to two separate SCRs connected in inverse parallel (i.e. anode of each connected to the cathode of the other) with gates commoned as shown in Fig. 8 (ii).

Therefore, a triac acts like a bidirectional switch i.e. it can conduct current in either direction. This is unlike an SCR which can conduct current only in one direction. Fig. 8 (iii) shows the schematic symbol of a triac.

The symbol consists of two parallel diodes connected in opposite directions with a single gate lead. It can be seen that even the symbol of triac indicates that it can conduct current for either polarity of the main terminals (MT1 and MT2) i.e. it can act as a bidirectional switch. The gate provides control over conduction in either direction

Then a triac has four possible triggering modes of operation as follows.

- **I + Mode = MT2 current positive (+ve), Gate current positive(+ve)**
- **I – Mode = MT2 current positive (+ve), Gate current negative(-ve)**
- **III + Mode = MT2 current negative (-ve), Gate current positive (+ve)**
- **III – Mode = MT2 current negative (-ve), Gate current negative(-ve)**

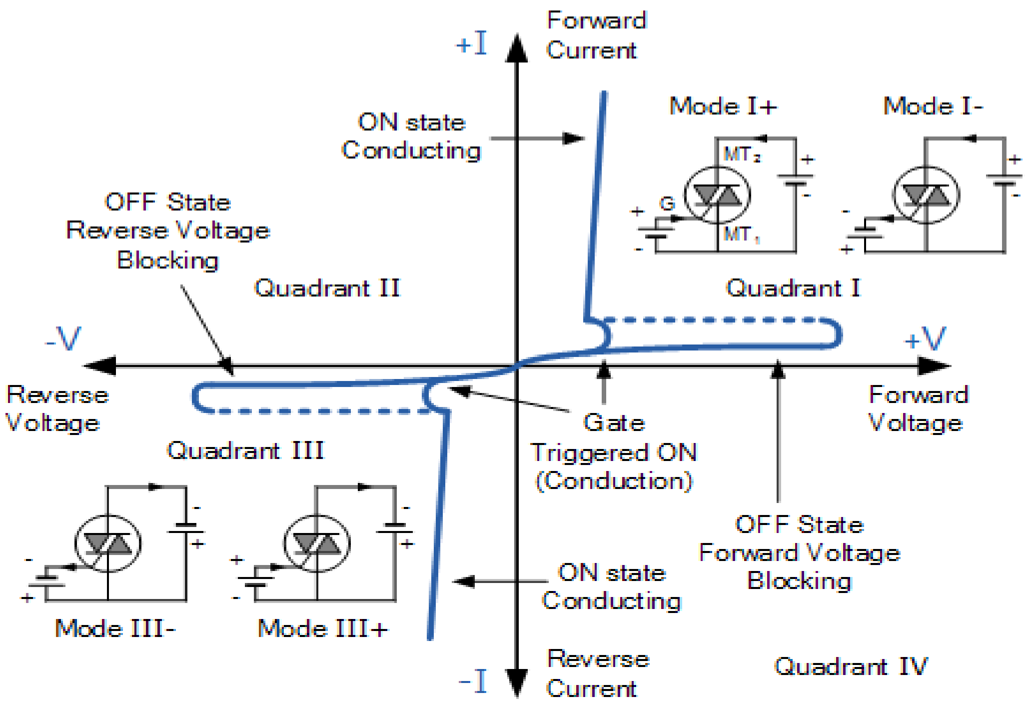


Fig 9 VI Characteristics of TRIAC

In Quadrant I, the triac is usually triggered into conduction by a positive gate current, labelled above as mode I+. But it can also be triggered by a negative gate current, mode I–. Similarly, in Quadrant III, triggering with a negative gate current, –IG is also common, mode III– along with mode III+. Modes I– and III+ are, however, less sensitive configurations requiring a greater gate current to cause triggering than the more common triac triggering modes of I+ and III–.

TRIAC OPERATION

Since a Triac is a bidirectional device and can have its terminals at various combinations of positive and negative voltages, there are four possible electrode potential combinations as given below

The triggering sensitivity is highest with the combinations 1 and 3 and are generally used. However, for bidirectional control and uniforms gate trigger mode sometimes trigger modes 2 and 3 are used. Trigger mode 4 is usually averted. Fig 10 (a) and (b) explain the conduction mechanism of a triac in trigger modes 1 & 3 respectively.

In trigger mode-1 the gate current flows mainly through the P_2N_2 junction like an ordinary thyristor. When the gate current has injected sufficient charge into P_2 layer the triac starts conducting through the $P_1N_1P_2N_2$ layers like an ordinary thyristor.

In trigger mode-2 the junction P2-N3 is forward biased, thus the electron is injected from N3 into P2. a current that flows in P2owards the N3 gate and thus P1N1P2N3 turns on as the gain of N3P2N1 transistor raises. this supplies current to N2 thus P1N1P2N2 conducts.

In trigger mode- 3t he gate current I_g forward biases the P_2P_3 junction and a large number of electrons are introduced in the P_2 region by N_3. Finally the structure $P_2N_1P_1N_4$ turns on completely.

In trigger mode-4 junction P2N3 is forward biased and the electron are injected from N3 TO P2 .the potential in N1 decreases and holes are injected from p2 to n1 this turns on the SCR P2N1P1N4

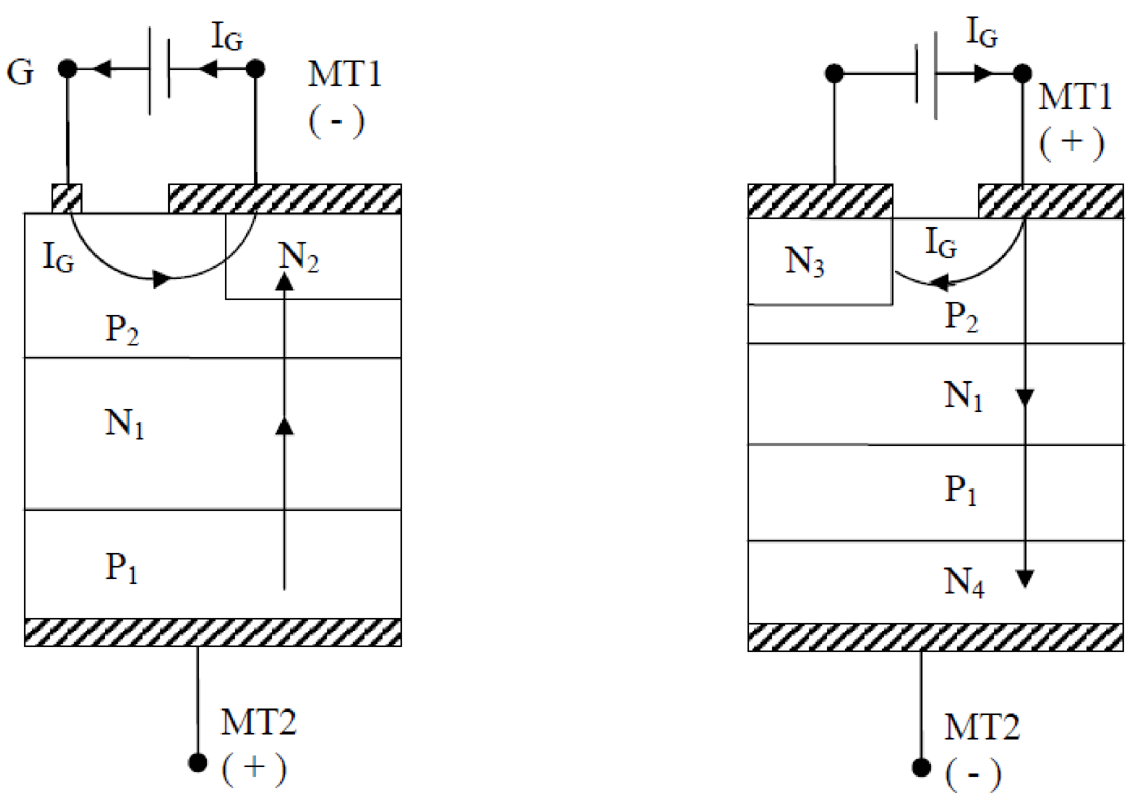


Fig 10

APPLICATIONS

The TRIAC as a bidirectional thyristor has various applications. Some of the popular applications of the

(i) In speed control of single-phase ac series or universal motors.

(ii) In food mixers and portable drills.

(iii) In lamp dimming and heating control.

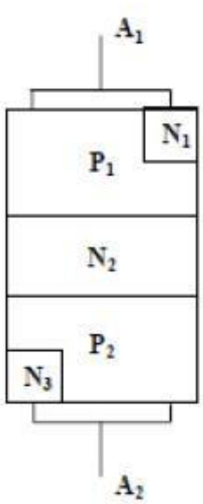
(iv) In zero-voltage switched ac relay

(v)Triacs are extensively used at power frequency ac load (eg heater, light, motors) control applications.

DIAC (Diode for Alternating Current)

A diac is a two-terminal, three layer bidirectional device which can be switched from its OFF state to ON state for either polarity of applied voltage the diac can be constructed in either npn or pnp form. the DIAC is a diode that conducts electrical current only after its breakover voltage, VBO,

The DIAC is a five layers and contains two terminal, anode A1 (or main terminal MT1) and anode A2 (or main terminal MT2) like a TRIAC just without a gate terminal.



Construction of DIAC

Symbol of DIAC

Fig 11

Fig. 11 shows the basic structure of a diac in pnp form. The two leads are connected to p-regions of silicon separated by an n-region. The structure of diac is very much similar to that of a transistor.

However, there are several imporant differences:

(i)There is no terminal attached to the base layer.

(ii) The three regions are nearly identical in size.

(iii) The doping concentrations are identical (unlike a bipolar transistor) to give the device symmetrical properties. Fig. 11(ii) shows the symbol of a diac

OPERATION.

When a positive or negative voltage is applied across the terminals of a diac, only a small leakage current IBO will flow through the device. As the applied voltage is increased, the leakage current will continue to flow until the voltage reaches the breakover voltage VBO. At this point, avalanche breakdown of the reverse-biased junction occurs and the device exhibits negative resistance i.e. current through the device increases with the decreasing values of applied voltage. The voltage across the device then drops to 'breakback' voltage VW.

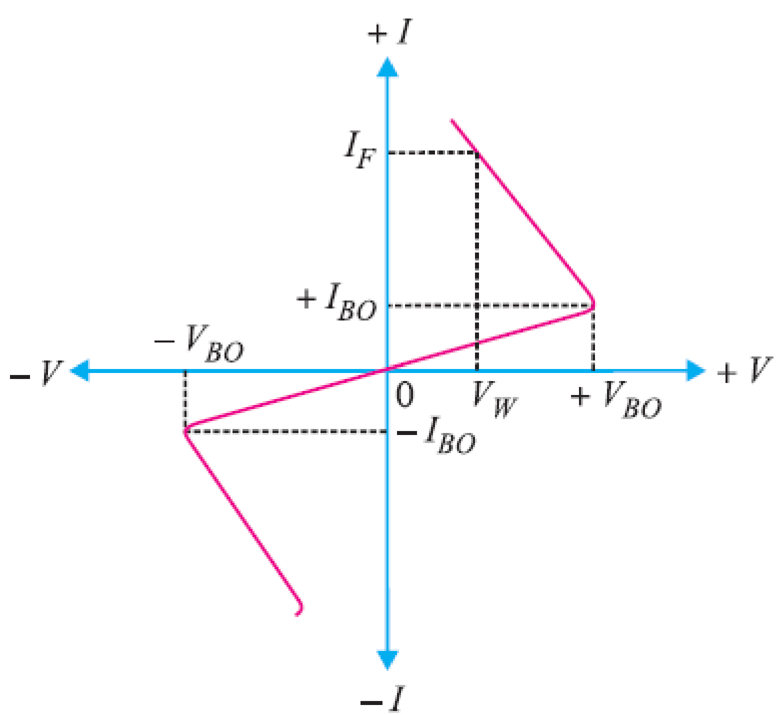


Fig 12

Fig. 12 shows the V-I characteristics of a diac. For applied positive voltage less than + VBO and negative voltage less than − VBO, a small leakage current (± IBO) flows through the device. Under such conditions, the diac blocks the flow of current and effectively behaves as an open circuit. The voltages + VBO and − VBO are the breakdown voltages and usually have a range of 30 to 50 volts. When the positive or negative applied voltage is equal to or greater than the breakdown voltage, diac begins to conduct and the voltage drop across it becomes a few volts. Conduction then continues until the device current drops below its holding current. Note that the breakover voltage and holding current values are identical for the forward and reverse regions of operation.

Diacs are used primarily for triggering of triacs in adjustable phase control of a.c. mains power. Some of the circuit applications of diac are

(i) light dimming

(ii) (ii) heat control and

(iii) (iii) universal motor speed control.

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. 13 (i) shows the basic *structure of a unijunction transistor. It consists of an n-type silicon bar with an electrical connection on each end. The leads 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. 13 (ii) shows the symbol of unijunction transistor. Note that emitter is shown closer to B2 than B1.

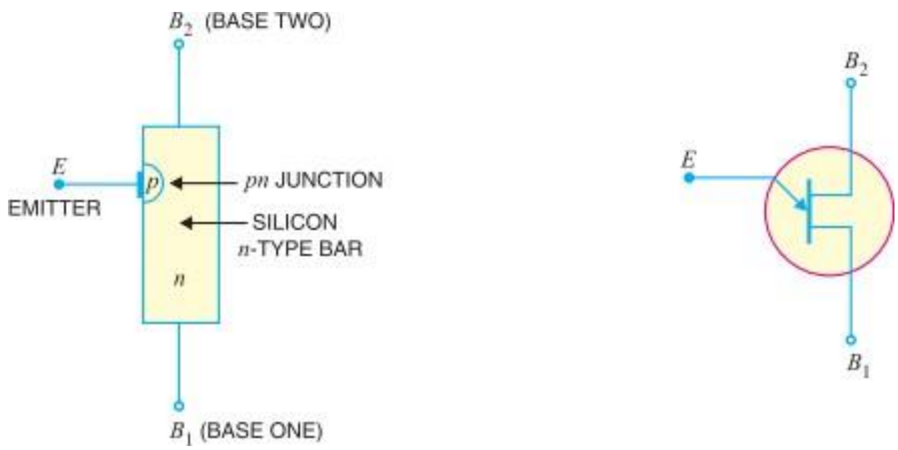


FIG13

(i)Since the device has one pn junction and three leads, it is commonly called a unijunction transistor (uni means single).

(ii) 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.

(iii) 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.

OPERATION.

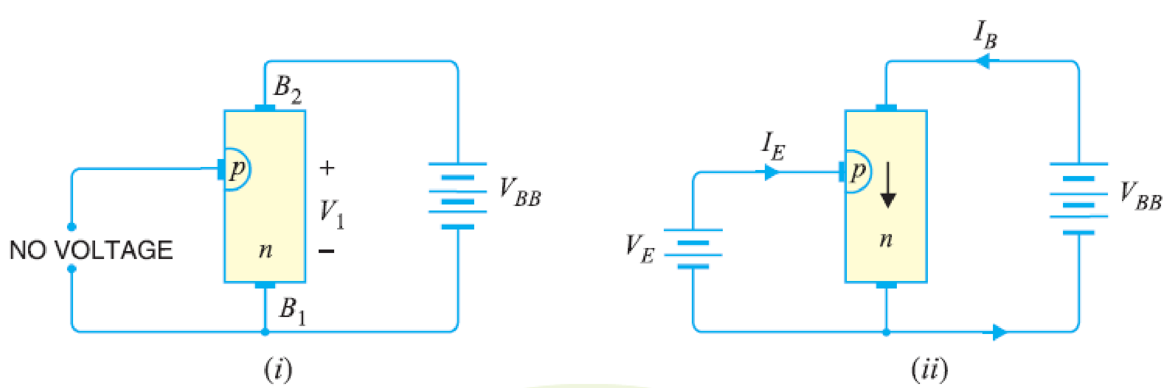


FIG 14

Fig. 14 shows the basic circuit operation of a unijunction transistor.

The device has normally B2 positive w.r.t. B1.

(i) If voltage VBB is applied between B2 and B1 with emitter open [See Fig. 14 (i)], 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 everse 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.

(ii) If a positive voltage is applied at the emitter [See Fig. 14 (ii)], 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.

(iii) 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.

CHARACTERISTICS OF UJT

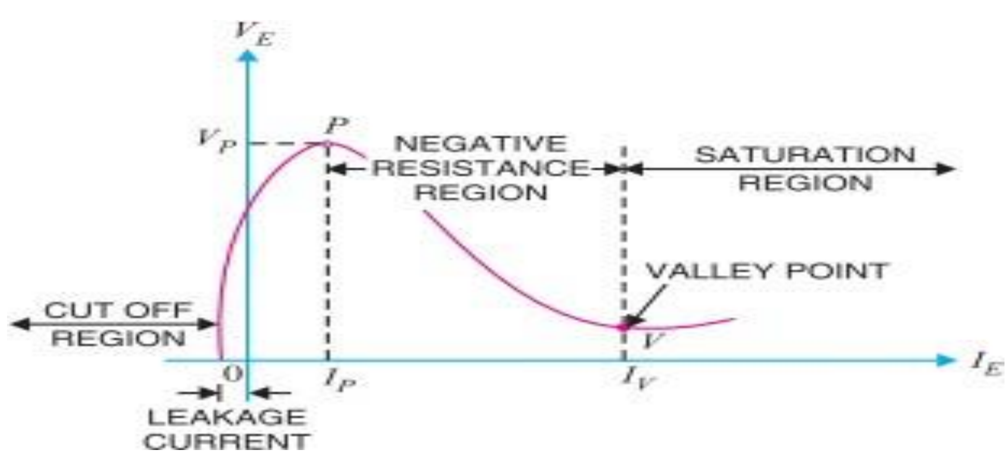


Fig 15

Fig. 15 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.

(ii) 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.

(iii) 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 :

(i) It is a low cost device.

(ii) It has excellent characteristics.

(iii) 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 select applications of the UJT are as follows:

(i) It is used to trigger SCRs and TRIACs

(ii) It is used in non-sinusoidal oscillators

(iii) It is used in phase control and timing circuits

(iv) It is used in saw tooth generators

(v) It is used in oscillator circuit design

SCHOTTY BARRIER DIODE

Schottky Diode:

It is also called Schottky barrier diode or hot-carrier diode.

A Schottky barrier diode is a metal semiconductor junction formed by bringing metal in contact with a moderately doped n type semiconductor material. A Schottky barrier diode is also called as known as Schottky or hot carrier diode. It is named after its inventor Walter H. Schottky, barrier stands for the potential energy barrier for electrons at the junction. It is a unilateral device conducting currents in one direction (Conventional current flow from metal to semiconductor) and restricting in the other.

Fig.16

- **The charge storage problem of P-N junction can be minimize or limited in schottky diodes.**
- **The potential barrier is set with a contact between a metal & semiconductor.**
- **The rectifying action is depends on majority carrier only.**
- **As the result there are is o excess minority carrier to recombination hence low level of reverse recovery time.**
- **These diodes are used as rectifier at a single frequency exceeding 300 MHz to 20 GHz.**

CONSTRUCTION SCHOTTKY BARRIER DIODE:

A Schottky barrier diode is shown in the figure 17

A metal–semiconductor junction is formed between a metal and a semiconductor, creating a Schottky barrier (instead of a semiconductor–semiconductor junction as in conventional diodes).Typical metals used are molybdenum, platinum, chromium or

tungsten,and certain silicides, e.g. palladium silicide and platinum silicide; andthe semiconductor would typically be n-type silicon.

The metal side acts as the anode and n-type semiconductor acts as the cathode of the diode. This Schottky barrier results in both very fast switching and low forward voltage drop.

The choice of the combination of the metal and semiconductor determines the forward voltage of the diode. Both n- and p-type semiconductors can develop Schottky barriers; the p-type typically has a much lower forward voltage.

As the reverse leakage current increases dramatically with lowering the forward voltage, it can not be too low; the usually employed range is about 0.5–0.7 V and p-type semiconductors are employed only rarely.

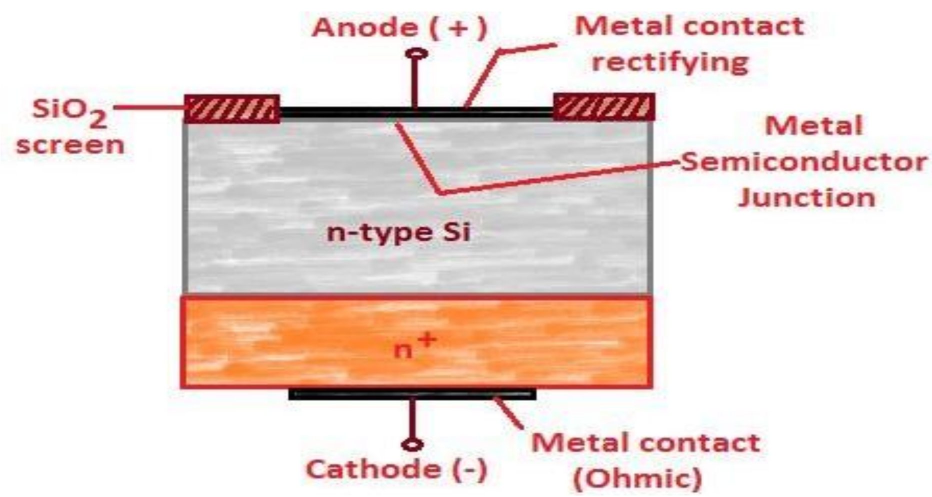


Fig 17

Schottky barrier diode is an extension of the oldest semiconductor device that is the point contact diode.Here,the metal-semiconductor interface is a surface ,Schottky barrier rather than a point contact.The Schottky doide is formed when a metal ,such as Aluminium ,is brought into contact with a moderately doped N-type semiconductor as shown on fig..It is a unipolar device because it has electrons as majority carriers on both sides of the junction.Hence ,there is no depletion layer formed near the junction.It shares the advantage of point contact diode in that there is no significant current from the metal to the semiconductor with reverse bias.Thus ,the delay present in the junction diodes due to hole-electron recombination time is absent here.hence,because of the large contact area between the metal and semiconductor than in the point contact diode,the forward resistance is lower and so is noise.

Below certain width the charge carriers can tunnel through the depletion region. At very high doping levels the junction does not behave as a rectifier anymore and becomes an ohmic contact. This can be used for simultaneous formation of ohmic.

The forward current is dominated by electron flow from semiconductor to metal and the reverse is mainly due to electron from metal to semiconductor. As there is very little minority carrier injection from semiconductor into metal, Schottky diodes are also said to be majority carrier devices. The diode is also referred to as hot carrier diode because when it is forward biased,conduction of electrons on the N-side gains sufficient energy to cross the junction and enter the metal. Since these electrons plunge into the metal with large energy, they are commonly called as hot carriers.

- Operation is due to the fact that the electrons in different material have different potential energy.
- N type semiconductors have higher potential energy as compare to electrons of metals.
- When these two are brought together in contact, there a flow of electron in both direction across the metal-semiconductor interface when contact is first made.
- A voltage is applied to the schottky diode such that the metal is positive with respect to semiconductor.
- The voltage will oppose the built in potential and makes it easier to current flow.

CHARACTERISTICS OF SCHOTTKY DIODE

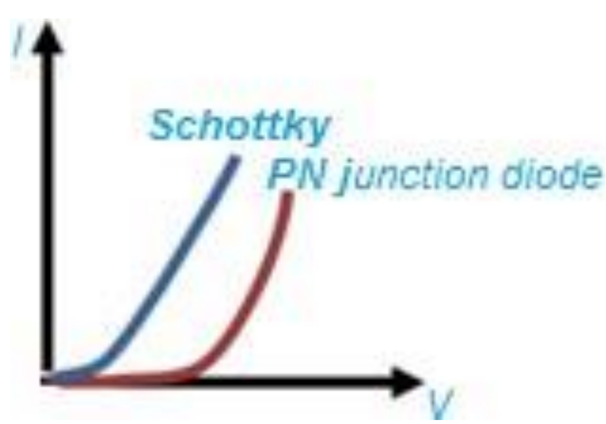


FIG .18

Above figure shows the V-I characteristics of a Schottky and a PN junction diode. The current in a PN junction diode is controlled by the diffusion of minority carriers whereas the current in the schottky diode results from the flow of majority carriers over the potential barrier at the metal-semiconductor junction.The reverse saturation current for a Schottky diode is larger than that of a PN junction diode.The storage time for a Schottky diode is theoretically zero.The schottky diode has a smaller turn-on voltage and shorter switching time than the PN junction diode.

ADVANTAGES :

- **Schottky diode turns on and off faster than ordinary P-N junction diode the basic reason behind this is that schottky diodes are based on majority carrier.**
- **As there is no minority carrier there is no worry about depletion layer.**

It has much less voltage overshoot

APPLICATIONS SCHOTTKY BARRIER DIODE:

- **Schottky diode can be used for rectification of signals of frequencies even exceeding 300 MHz.**
- **It is commonly used in switching power supplies at frequencies of 20 GHz**
- **Its low noise figure finds application in sensitive communication receivers likeradars.**
- **It is also used in clipping and clamping circuits and in computer gating.**
- **Schottky barrier diodes are used in bipolar transistor TTL based 74LS (low power Schottky) and 74S (Schottky) families of logic circuits . The Schottky diode by preventing the BJT going into hard saturation reduces the switching time of BJT from saturation to cut off.**
- **Schottky diodes are often used as ant saturation clamps on transistors.**
- **They play an important role in GaAs circuits.**
- **They are used as rectifiers in high power applications circuits.**
- **Schottky Barrier Diodes are used in voltage clamping applications.**
- **Schottky Barrier Diodes are used in stand-alone photo voltaic systems**
- **They are used in radio frequency applications as mixer (or) detector diode**

VARACTOR DIODE

The varactor diode was named because of the variable reactor or variable reactance or variable capacitor or variable capacitance property of these diodes. A varactor diode is considered as a special type of diode that is widely used in the electronics industry and is used in various electronics applications. Varactor diode is also a semiconductor microwave solid-state device, it is frequently used in applications where variable capacitance is desired which can be achieved by controlling voltage.

Varactor diodes are also termed as varicap diodes, in fact, these days they are usually termed as varactor diodes. Even though the variable capacitance effect can be exhibited by the normal diodes (P-N junction diodes), but, varactor diodes are preferred for giving the desired capacitance changes as they are special types of diodes. These diodes are specially manufactured and optimized such that they enables a very high range of changes in capacitance. Varactor diodes are again classified into various types based on the varactor diode junction properties. And, these are termed as abrupt varactor diodes, gallium-arsenide varactor diodes, and hyperabrupt varactor diodes.

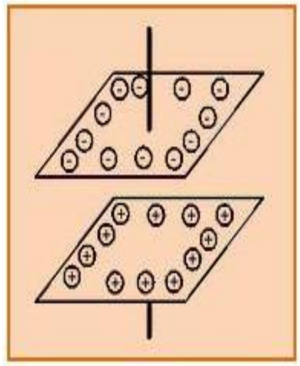
The symbol of varactor diode is shown in the Fig 19

Fig 19

The varactor diode symbol consists of the capacitor symbol at one end of the diode that represents the variable capacitor characteristics of the varactor diodes. n general, it looks like a normal PN- junction diode in which one terminal is termed as the cathode and the other terminal is termed as anode. Here, varactor diode consists of two lines at one end (cathode end of normal diode) that indicates the capacitor symbol.

VARACTOR DIODE WORKING

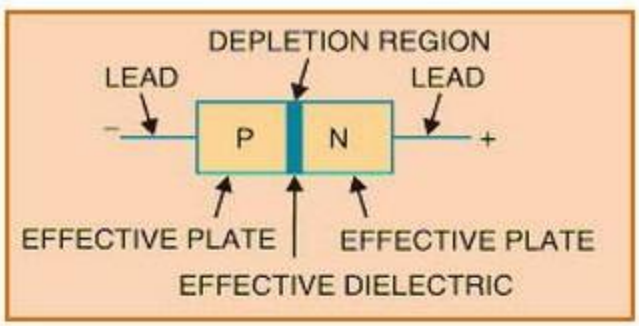
To understand the working principle of the varactor diode, we must know what is a capacitor and how can we change the capacitance. Let us consider the capacitor that consists of two plates separated by an insulating dielectric as shown in the figure 20.



Capacitor

Fig 20

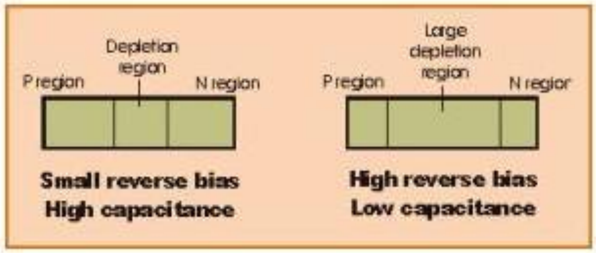
We know that the capacitance of an electrical capacitor is directly proportional to the area of the plates, as the area of the plates increases the capacitance of the capacitor increases. Consider the reverse biased mode of the diode, in which P-type region and N-type region are able to conduct and thus can be treated as two plates. The depletion region between the P-type and N-type regions can be considered as insulating dielectric. Thus, it is exactly similar to the capacitor shown above.



Varactor Diode with P-N Junctoin and Depletion Region

Fig 21

The size of the depletion region of diode changes with change in reverse bias. If the varactor diode reverse voltage is increased, then the depletion region size increases. Similarly, if the varactor diode reverse voltage is decreased, then the depletion region size decreases or narrows. Hence, by varying the reverse bias of the varactor diode the capacitance can be varied



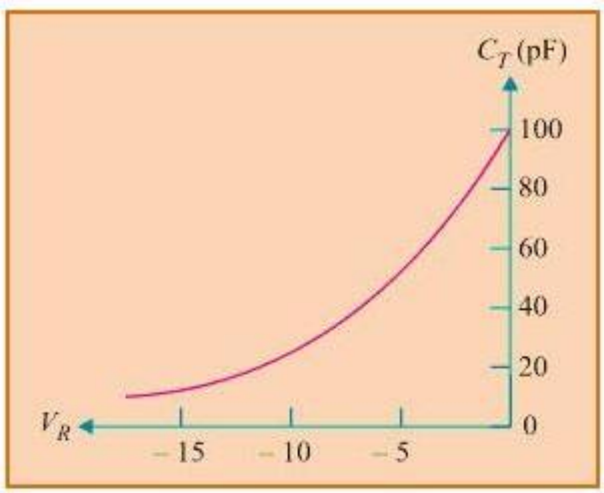
Variation of Capacitance with Variation in Depletion Region of Varactor Diode

Fig 22

VARACTOR DIODE CHARACTERISTICS

The varactor diodes have the following significant characteristics:

- **Varactor diodes produces considerably less noise compared to other conventional diodes.**
- **These diodes are available at low costs.**
- **Varactor diodes are more reliable.**
- **The varactor diodes are small in size and hence, they are very light weight.**
- **There is no useful purpose of varactor diode operated when it is operated in forward bias.**
- **Increase in reverse bias of varactor diode increases the capacitance as shown in the figure below.**



Characteristics of Varactor Diode

Fig 23

APPLICATIONS

Few important applications of varactor diodes can be listed as follows:

- **RF Filters**
- **Voltage Controlled Oscillators (VCOs)**
- **Varactor diodes can be used as frequency modulators.**
- **In microwave receiver LO, varactor diodes can be used as frequency multipliers.**
- **Varactor diodes can be used as RF phase shifters.**
- **Varactor diodes are used to vary the capacitance in variable resonant tank LC circuits. Since the junction capacitance of a varactor is in the pF range, it is suitable for use in highfrequency circuits.**
- **automatic frequency control device,**
- **FM modulator,**
- **adjustable band-pass filter**
- **Parametric amplifier**

TUNNEL DIODE

This diode was first introduced by Dr. Leo Easki in 1958.

A tunnel diode is a pn junction that exhibits negative resistance between two values of forward voltage (i.e., between peak-point voltage and valley-point voltage).

A conventional diode exhibits *positive resistance when it is forward biased or reverse biased. However, if a semiconductor junction diode is heavily doped with impurities, it exhibits negative resistance (i.e. current decreases as the voltage is increased) in certain regions in the forward direction. Such a diode is called tunnel diode

CONSTRUCTION

It is a high-conductivity two-terminal P-N junction diode having doping density about 1000 times higher as compared to an ordinary junction diode. This heavy doping produces following three unusual effects :

Firstly, it reduces the width of the depletion layer to an extremely small value (about 0.00001 mm).

Secondly, it reduces the reverse breakdown voltage to a very small value (approaching zero) with the result that the diode appears to be broken down for any reverse voltage.

Thirdly, it produces a negative resistance section on the V/I characteristic of the diode. It is called a tunnel diode because due to its extremely thin depletion layer, electrons are able to tunnel through the potential barrier at relatively low forward bias voltage (less than 0.05 V).

Such diodes are usually fabricated from germanium, gallium-arsenide (GaAs) and gallium antimonide (GaSb). The commonly-used schematic symbols for the diode are shown in fig 23. It should be handled with caution because being a low-power device, it can be easily damaged by heat and static electricity.

THEORY.

The tunnel diode is basically a pn junction with heavy doping of p-type and n-type semiconductor materials. In fact, a tunnel diode is doped approximately 1000 times as heavily as a conventional diode. This heavy doping results in a large number of majority carriers. Because of the large number of carriers, most are not used during the initial recombination that produces the depletion layer. As a result, the depletion layer is very narrow. In comparison with conventional diode, the depletion layer of a tunnel diode is 100 times narrower. The operation of a tunnel diode depends upon the tunneling effect and hence the name.

Tunneling effect. The heavy doping provides a large number of majority carriers. Because of the large number of carriers, there is much drift activity in p and n sections. This causes many valence electrons to have their energy levels raised closer to the conduction region. Therefore, it takes only a very small applied forward voltage to cause conduction.

The movement of valence electrons from the valence energy band to the conduction band with little or no applied forward voltage is called tunneling. Valence electrons seem to tunnel through the forbidden energy band.

As the forward voltage is first increased, the diode current rises rapidly due to tunneling effect. Soon the tunneling effect is reduced and current flow starts to decrease as the forward voltage across the diode is increased. The tunnel diode is said to have entered the negative resistance region. As the voltage is further increased, the tunneling effect plays less and less part until a valley-point is reached. From now onwards, the tunnel diode behaves as ordinary diode i.e., diode current increases with the increase in forward voltage.

V-I CHARACTERISTIC.

shows the V-I characteristic of a typical tunnel diode.

As the forward voltage across the tunnel diode is increased from zero, electrons from the nregion "tunnel" through the potential barrier to the p-region. As the forward voltage increases, the diode current also increases until the peak-point P is reached. The diode current has now reached peak current IP (= 2.2 mA) at about peak-pointvoltage VP (= 0.07 V). Until now the diode has exhibited positive resistance. (ii) As the voltage is

increased beyond VP, the tunneling action starts decreasing and the diode current decreases as the forward voltage is increased until valley-point V is reached at valley- point voltage VV (= 0.7V). In the region between peak-point and valley-point (i.e., between points P and V), the diode exhibits negative resistance i.e., as the forward bias is increased, the current decreases. This suggests that tunnel diode, when operated in the negative resistance region, can be used as an oscillator or a switch.

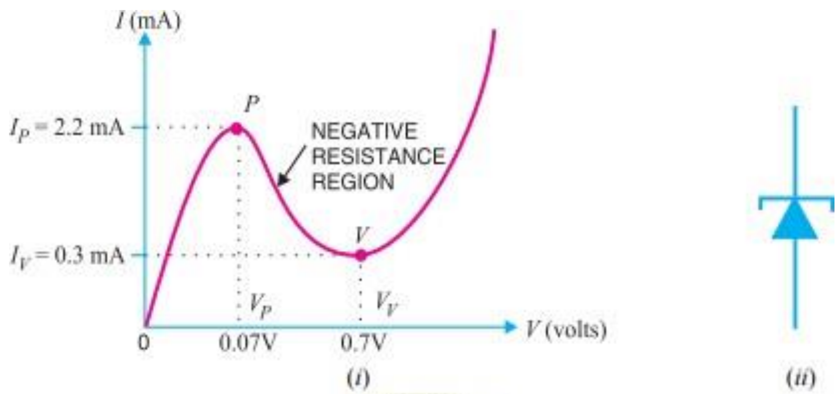


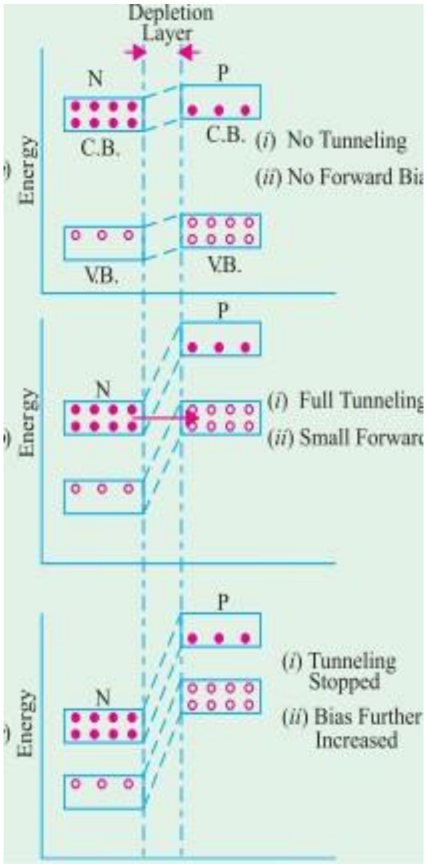
Fig. 7.18

Fig 24

(iii) When forward bias is increased beyond valley-point voltage VV (= 0.7 V), the tunnel diode behaves as a normal diode. In other words, from point V onwards, the diode current increases with the increase in forward voltage i.e., the diode exhibits positive resistance once again.It may be noted that a tunnel diode has a high reverse current but operation under this condition is not generally used.

Tunneling Effect

In a normally-doped P-N junction, the depletion layer is relatively wide and a potential barrier exists across the junction. The charge carriers on either side of the junction cannot cross over unless they possess sufficient energy to overcome this barrier (0.3 V for Ge and 0.7 V for Si). As is well-known, width of the depletion region depends directly on the doping density of the semiconductor. If a P-N junction is doped very heavily (1000 times or more)*, its depletion layer becomes extremely thin (about 0.00001 mm). It is found that under such conditions, many carriers can 'punch through' the junction with the speed of light even when they do not possess enough energy to overcome the potential barrier. Consequently, large forward current is produced even when the applied bias is much less than 0.3 V. This conduction mechanism in which charge carriers (possessing very little energy) bore through a barrier directly instead of climbing over it is called tunneling



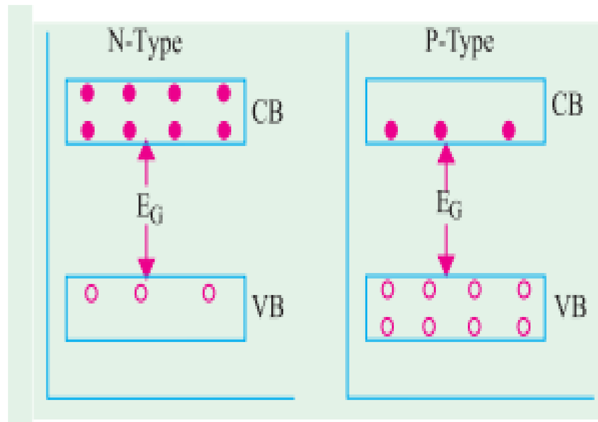


Fig 25

EXPLANATION

Energy band diagrams (EBD) of N-type and Ptype semiconductor materials can be used to explain this tunneling phenomenon. Fig. 54.16 shows the energy band diagram of the two types of silicon separately. As explained earlier (Art. 51.21), in the N- type semiconductor, there is increased concentration of electrons in the conduction band. It would be further increased under heavy doping. Similarly, in a Ptype material, there is increased concentration of holes in the valence band for similar reasons. (a) No Forward Bias When the N-type and P-type materials are joined, the EBD under no-bias conditiion becomes as shown in Fig. 24(a).

The junction barrier produces only a rough alignment of the two materials and their respective valence and conduction bands. As seen, the depletion region between the two is extremely narrow due to very heavy doping on both sides of the junction. The potential hill is also increased as shown.

(b) Small Forward Bias When a very small forward voltage (≅ 0.1 V) is applied, the EBDs become as shown in Fig. 54.17 (b). Due to the downward movement of the N- region, the P-region valence band becomes exactly aligned with the N-region

conduction band. At this stage, electrons tunnel through the thin depletion layer with the velocity of light thereby giving rise to a large current called peak current Ip.

(c) Large Forward Bias When the forward bias is increased further, the two bands get out of alignment as shown in Fig. 24(c). Hence, tunneling of electrons stops thereby decreasing the current. Since current decreases with increase in applied voltage (i.e. dV/dI is negative), the junction is said to possess negative resistance at this stage. This resistance increases throughout the negative region. However, it is found that when applied forward voltage is increased still further, the current starts increasing once again as in a normal junction diode.

APPLICATIONS

Tunnel diode is commonly used for the following purposes :

1. as an ultrahigh-speed switch-due to tunneling mechanism which essentially takes place at the speed of light. It has a switching time of the order of nanoseconds or even picoseconds;

2. as logic memory storage device − due to triple-valued feature of its curve for current.

3. as microwave oscillator at a frequency of about 10 GHz − due to its extremely small capacitance and inductance and negative resistance.

4. in relaxation oscillator circuits − due to its negative resistance. In this respect, it is very similar to the unijunction transistor.

ADVANTAGES AND DISADVANTAGES

The advantages of a tunnel diode are :

1. low noise,

2. ease of operation,

3. high speed,

4. low power,

5. Insensitivity to nuclear radiations T

The disadvantages are

: 1. the voltage range over which it can be operated properly is 1 V or less;

2. being a two-terminal device, it provides no isolation between the input and output circuits

PIN diode

A PIN diode is a diode with a wide, undoped intrinsic semiconductor region between a p-type semiconductor and an n-type semiconductor region. The p-type and n-type regions are typically heavily doped because they are used for ohmic contacts.

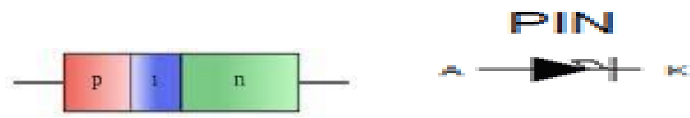


Fig 26

the PIN diode consists of a semiconductor diode with three layers. The usual P and N regions are present, but between them is a layer of intrinsic material a very low level of doping. This may be either N-type or P-type,

The thickness of the intrinsic layer is normally very narrow, typically ranging from 10 to 200 microns. The outer P and N-type regions are then heavily doped

here is very lightly doped wide region between P and N regions. Wide I – region makes them inefficient rectifiers. Under zero or Reverse Bias PIN diode has low capacitance so high resistance to RF signal. Under FB a typical PIN diode will have very low resistance (typical 1 Ω) an RF conductor. It makes a god RF switch

The PIN diode has heavily doped p-type and n-type regions separated by an intrinsic region. When reverse biased, it acts like an almost constant capacitance and when forward biased it behaves as a variable resistor.

The built in field stretches over the intrinsic region, causing minority carriers to be swept out by the field over a larger volume. It is often used for light detectors, and some high efficiency solar cells.

The capacitance between the P and N region decreases because of the increased seperation between P and N region.thid advantage allow the PIN diode to have fast response time. Hence these diode are useful at very high frequencies (above 300MHZ)

There is a great er electron hole pair generation because of the increased electricfield between the P and N region.this advantage allows the PIN diode to process even the weak signal

OPERATION

When P n region is unbiased (no voltage is applied acrossthe diode)ther is a diffusion ofelectron aand holesacross the junction due to the different concentration of atoms in the P I N region

The diffusion of electron s and holes produce a depletion layer across the PI and NI junction as shown in Fig.7-21(b). The depletion layer penetrate to a little distance in the P –type and N –type semiconductor regions but to a larger distance in the I-region. Under such condition , the device has a high value of resistance.

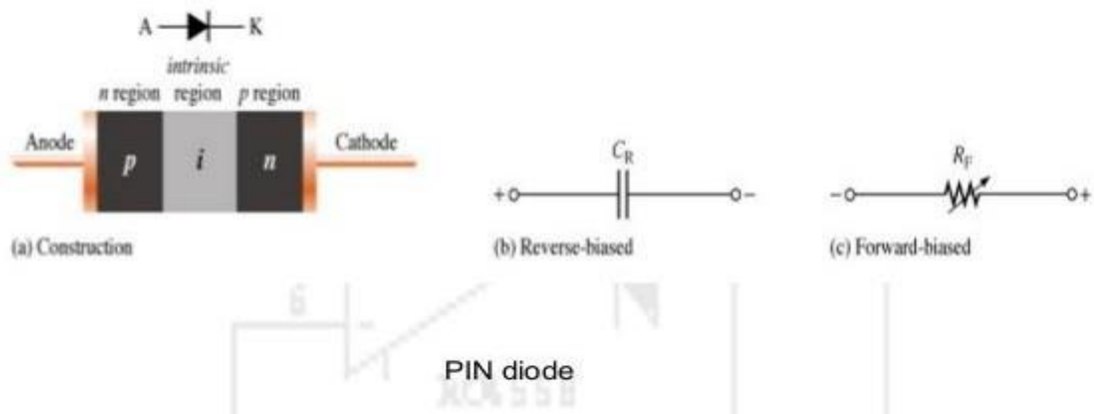


Fig 27

When the PIN diode is forward biased, the width of the depletion layer s decreases. As a result of this, more carriers are injected into the I-region. This reduces the resistance of the I-region. I the depletion layer is not thick, then the I-region becomes flooded with the carriers at a suitable bias. Thus, when a PIN diode is forward biased, it acts like a variable resistance as shown in fig 27 The forward resistance of an intrinsic region decreases with the increasing current.

On the other, when the PIN diode is reverse biased, the depletion layers become thicker. As the reverse bias is increased , the thickness of the depletion layer increases till the I-region becomes free of mobile caries. The reverse bias , at which this happens, is called swept out voltage. At this stage the PIN diode acts like an almost constant capacitance as shown in Fig. 27

APPLICATION

The PIN diode is used in a number of areas as a result of its structure proving some properties which are of particular use.

- **High voltage rectifier: The PIN diode can be used as a high voltage rectifier. The intrinsic region provides a greater separation between the PN and N regions, allowing higher reverse voltages to be tolerated.**
- **RF switch: The PIN diode makes an ideal RF switch. The intrinsic layer between the P and N regions increases the distance between them. This also decreases the capacitance between them, thereby increasing he level of isolation when the diode is reverse biased.**
- **Photodetector: As the conversion of light into current takes place within the depletion region of a photdiode, increasing the depletion region by adding the intrinsic layer improves the performance by increasing he volume in which light conversion occurs.**

These are three of the main applications for PIN diodes, although they can also be used in some other areas as well

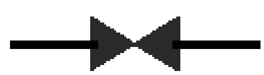
GUNN DIODE

Gunn diode basics

the Gunn diode is a unique component - even though it is called a diode, it does not contain a PN diode junction. The Gunn diode or transferred electron device can be termed a diode because it does have two electrodes. It depends upon the bulk material properties rather than that of a PN junction. The Gunn diode operation depends on the fact that it has a voltage controlled negative resistance.

GUNN DIODE SYMBOL

The Gunn diode symbol used in circuit diagrams varies. Often a standard diode is seen in the diagram, however this form of Gunn diode symbol does not indicate the fact that the Gunn diode is not a PN junction. Instead another symbol showing two filled in triangles with points touching is used as shown below.



Gunn diode symbol

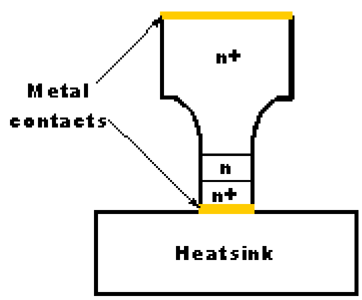
Fig 28

GUNN DIODE CONSTRUCTION

Gunn diodes are fabricated from a single piece of n-type semiconductor. The most common materials are gallium Arsenide, GaAs and Indium Phosphide, InP. However other materials including Ge, CdTe, InAs, InSb, ZnSe and others have been used. The device is simply an n-type bar with n+ contacts. It is necessary to use n-type material because the transferred electron effect is only applicable to electrons and not holes found in a p-type material.

Within the device there are three main areas, which can be roughly termed the top, middle and bottom areas.

The most common method of manufacturing a Gunn diode is to grow and epitaxial layer on a degenerate n+ substrate. The active region is between a few microns and a few hundred micron thick. This active layer has a doping level between $10^{14}cm^{-3}$ and $10^{16}cm^{-3}$ - this is considerably less than that used for the top and bottom areas of the device. The



thickness will vary according to the frequency required

A discrete Gunn diode with the active layer mounted onto a heatsink for efficient heat transfer

. Fig 29

The top n+ layer can be deposited epitaxially or doped using ion implantation. Both top and bottom areas of the device are heavily doped to give n+ material. This provides the required high conductivity areas that are needed for the connections to the device.

Devices are normally mounted on a conducting base to which a wire connection is made. The base also acts as a heat sink which is critical for the removal of heat. The connection to the other terminal of the diode is made via a gold connection deposited onto the top surface. Gold is required because of its relative stability and high conductivity.

During manufacture there are a number of mandatory requirements for the devices to be successful - the material must be defect free and it must also have a very uniform level of doping.

For the construction of these diodes, only N-type material is used, which is due to the transferred electron effect applicable only to N-type materials and is not applicable to the P-type materials. The frequency can be varied by varying the thickness of the active layer while doping

GUNN DIODE'S WORKING

This diode is made of a single piece of N-type semiconductor such as Gallium Arsenide and InP (Indium Phosphide). GaAs and some other semiconductor materials have one extra-energy band in their electronic band structure instead of having only two energy bands, viz. valence band and conduction band like normal semiconductor materials. These GaAs and some other semiconductor materials consist of three energy bands, and this extra third band is empty at initial stage.

If a voltage is applied to this device, then most of the applied voltage appears across the active region. The electrons from the conduction band having negligible electrical resistivity are transferred into the third band because these electrons are scattered by the applied voltage. The third band of GaAs has mobility which is less than that of the conduction band.

Because of this, an increase in the forward voltage increases the field strength (for field strengths where applied voltage is greater than the threshold voltage value), then the number of electrons reaching the state at which the effective mass increases by decreasing their velocity, and thus, the current will decrease.

Thus, if the field strength is increased, then the drift velocity will decrease; this creates a negative incremental resistance region in V-I relationship. Thus, increase in the voltage will increase the resistance by creating a slice at the cathode and reaches the anode. But, to maintain a constant voltage, a new slice is created at the cathode. Similarly, if the voltage decreases, then the resistance will decrease by extinguishing any existing slice.

GUNN DIODE'S CHARACTERISTICS

The current-voltage relationship characteristics of a Gunn diode are shown in the above graph with its negative resistance region. These characteristics are similar to the characteristics of the tunnel diode.

As shown in the above graph, initially the current starts increasing in this diode, but after reaching a certain voltage level (at a specified voltage value called as threshold voltage

value), the current decreases before increasing again. The region where the current falls is termed as a negative resistance region, and due to this it oscillates. In this negative resistance region, this diode acts as both oscillator and amplifier, as in this region, the diode is enabled to amplify signals.

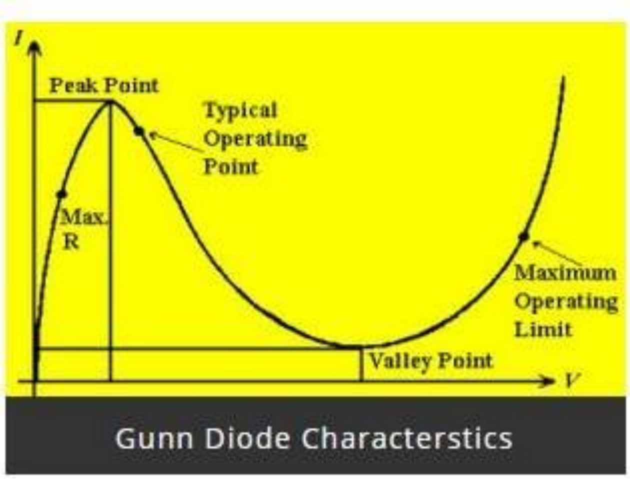


Fig 30

GUNN DIODE'S APPLICATIONS

- **Used as Gunn oscillators to generate frequencies ranging from 100mW 5GHz to 1W 35GHz outputs. These Gunn oscillators are used for radio communications, military and commercial radar sources.**
- **Used as sensors for detecting trespassers, to avoid derailment of trains.**
- **Used as efficient microwave generators with a frequency range of up to hundreds of GHz.**
- **Used for remote vibration detectors and rotational speed measuring tachometers.**
- **Used as a microwave current generator (Pulsed Gunn diode generator).**
- **Used in microwave transmitters to generate microwave radio waves at very low powers.**
- **Used as fast controlling components in microelectronics such as for the modulation of semiconductor injection lasers.**
- **Used as sub-millimeter wave applications by multiplying Gunn oscillator frequency with diode frequency.**
- **Some other applications include door opening sensors, process control devices, barrier operation, perimeter protection, pedestrian safety systems, linear distance indicators, level sensors, moisture content measurement and intruder alarms.**

LASERDIODE

A laser diode is nothing but the p-n junction combined with an optical resonator. This p- n junction constitutes a diode and it is operated in forward bias. The applied current generates the photons at the junction and further collision results the emission of more photons. If the carrier density within the p-n junction surpasses a certain value the light generated will be amplified and will finally yield the laser emission.

One of the peculiarity of the laser light is given as, it is monochromatic in nature, which means that it consists of a single color. So it is referred to as coherent light which means that a light with a single wavelength. In the case of incoherent light, it has a wide band of wavelengths.

Laser Diode Symbol

The given figures show the symbol and basic construction of a laser diode. A laser diode consists of p-n junction which is made up of two doped gallium arsenide layers. The two ends are flat as well as parallel to each other. One end is highly reflective (mirror) and the other one is partially reflective in nature. The depletion layer length depends on the wavelength of the emitted light.

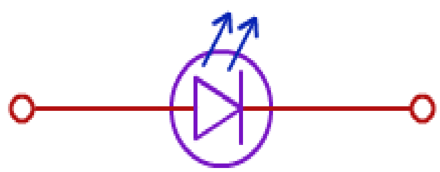


Fig 31

CONSTRUCTION

Fig shows the structure of an edge emitting laser diode. this type of structures' called febry-perot laser. As seen from the fig , a PN junction is formed by two layer of doped gallium arsenide(GaAs). The length of the PN junction bears a precise relation ship with the wave length of the light to be emitted. As seen there is a highly reflective surface at one endof the junction and a partially reflective surface at the other end .external leads provide the anode and cathode connections

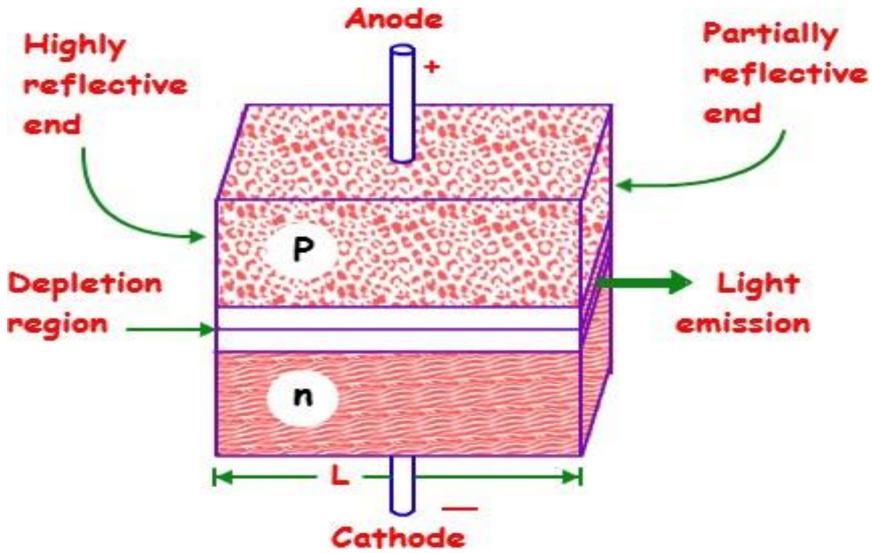


Fig 32

LASER DIODE THEORY BASICS

There are three main processes in semiconductors that are associated with light:

- ***Light absorption:*** **Absorption occurs when light enters a semiconductor and its energy is transferred to the semiconductor to generate additional free electrons and holes. This effect is widely used and enables devices like to photo-detectors and solar cells to operate.**
- ***Spontaneous emission:*** **The second effect known as spontaneous emission occurs in LEDs. The light produced in this manner is what is termed incoherent. In other words the frequency and phase are random, although the light is situated in a given part of the spectrum.**
- ***Stimulated emission:*** **Stimulated emission is different. A light photon entering the semiconductor lattice will strike an electron and release energy in the form of another light photon. The way in which this occurs releases this new photon of identical wavelength and phase. In this way the light that is generated is said to be coherent.**

LASER DIODE WORKING

The working principle of laser diode is given below. If the diode is set to be in forward bias using an external source, the electrons cross the junction and combine with the hole as in normal diodes. During this process, photons were released. These newly released photons collide with other atoms which causes further production of photons. If we increase the forward bias current more photons are produced due to the collision of each other. Some of the photons reflected back from the depletion region, during the reflection again collide with other atoms and produce the photons. These reflections and generation of new photons results the intense laser beam and this beam pass through the partially reflected area of the p-n junction.

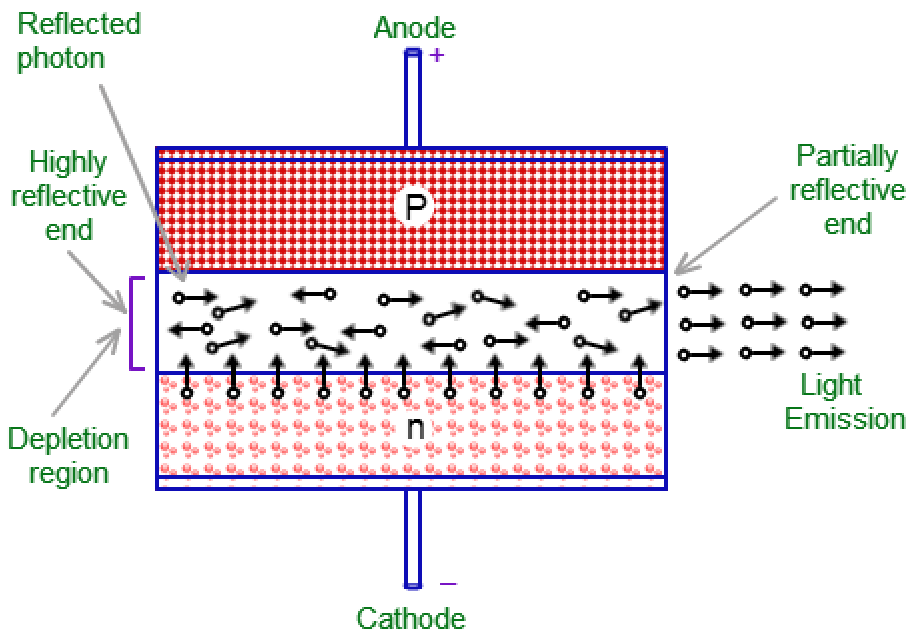


Fig 33

CHARACTERISTICS OF LASER DIODE

Thresholdcondition:

Threshold current is the most important and basic parameter for laser diodes. Incident spontaneous emission light propagating to the reflection mirror is amplified by stimulated emission and comes back to initial position after a round trip inside the laser cavity.

This process is subject to losses arising from light going through or diffracting at the reflection mirrors and scattering or absorption within an active light emitting medium. Light get attenuated if the total loss is greater than the gain. Injected current helps to strengthens the amplification light in the laser diode and when the gain and loss are balanced, initial light intensity becomes equal to the returned light intensity, this condition is referred to as a threshold.

A diode laser oscillates above the threshold when the gain is high enough Output power is one of the important parameters to characterize a diode laser. The figure shows an experimental result, which depicts the output power of a typical continuous wave in a semiconductor diode laser as a function of injection current. When the forward bias current is low, the laser diode operates like a light emitting diodes (LEDs) where the carrier density in the active layer is not high enough for population inversion, spontaneous emission is dominated in this region. As the bias increases, population inversion occurs, stimulated emission becomes dominant at a certain bias current, the current at this point is called threshold current. The injection current above the threshold induces the abrupt onset of laser action and coherent light is emitted from the diode laser. The laser threshold current is evaluated by extrapolating the linear part of the characteristic to zero output power.

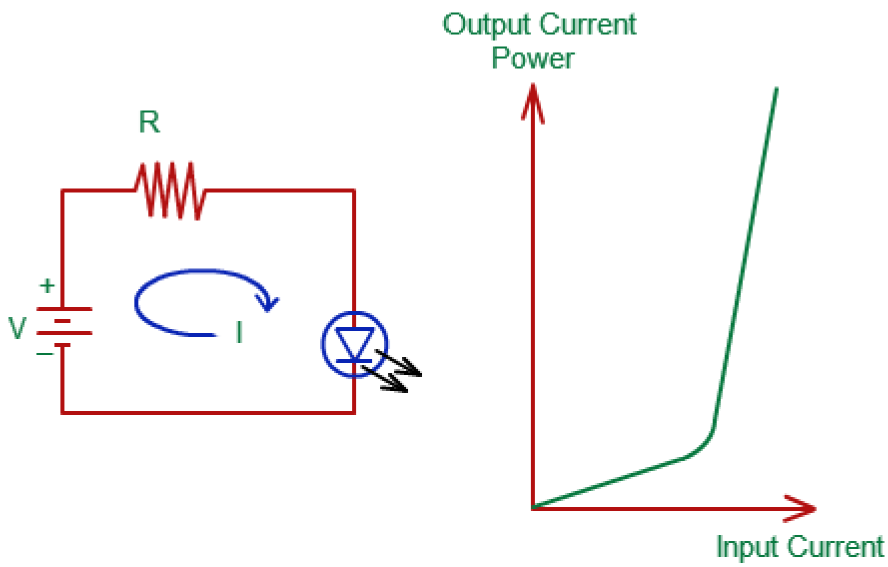


Fig 34

Laser diode technology has a number of advantages:

Power capability: Laser diodes are able to provide power levels from a few milliwatts right up to a few hundreds of watts.

Efficiency: Laser diode efficiency levels can exceed 30%, making laser diodes a particularly efficient method of generating coherent light.

Coherent light: The very nature of a laser is that it generates coherent light. This can be focussed to a diffraction limited spot for high density optical storage applications.

Rugged construction: Laser diodes are completely solid state and do not require fragile glass elements or critical set-up procedures. Accordingly they are able to operate under harsh conditions.

Compact: Laser diodes can be quite small allowing for laser diode technology to provide a very compact solution.

Variety of wavelengths: Using the latest technology and a variety of materials, laser diode technology is able to generate light over a wide spectrum. The use of blue light having a short wavelength allows for tighter focussing of the image for higher density storage.

Modulation: It is easy to modulate a laser diode, and this makes laser diode technology ideal for many high data rate communications applications. The modulation is achieved by directly modulating the drive current to the laser diode. This enables frequencies up to several GHz to be achieved for applications such as high-speed data communications.

APPLICATION

The use of LASER is in medical equipment used in surgery and in consumer product like compact disk(CD)Player, laser printers, hologram scanners etc

Some of the applications of laser diode is given below:

1. **To make measuring equipments**
2. **Pumping of fibre and solid state lasers**
3. **Medical equipments**
4. **Printing technology**
5. **Lighting**
6. **Material processing**
7. **For scientific research.**

SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND COMMMUNICATION ENGINEERING

UNIT - V

ELECTRONIC DEVICES – SECA1101

UNIT 5 POWER DEVICES AND DISPLAY DEVICES

Power BJT- Power MOSFET- DMOS-VMOS, CRO, LASER diode, Operation of LCDs, Plasma, LED, Opto-Coupler, Solar cell, CCD.

Power BJT

The transistor which is used for controlling large voltage and current is a power BJT (bipolar transistor) is a power transistor. It is also known as a voltage-current control device that operates in 4 regions cut-off, active, quasi saturation, and hard saturation based on the supplies given to the transistor. The three-terminal device which is designed specifically to control high current – voltage rating and handle a large number of power levels in a device or a circuit is a power transistor. The classification of power transistor **include the following.**

Operation of Power Transistor

Power Transistor BJT works in four regions of operation they are

- **Cut off region**
- **Active region**
- **Quasi saturation region**
- **Hard saturation region.**

A power transistor is said to be in a cut off mode if the n-p-n power transistor is connected in reverse bias where

case(i): The base terminal of the transistor is connected to negative and emitter terminals of the transistor is connected to positive, and
case(ii): The collector terminal of the transistor is connected to the negative and base terminal of the transistor is connected to positive that is base-emitter and collector-emitter is in reverse bias

Hence there will be no flow of output current to the base of the transistor where IBE = 0, and also there will be no output current flowing through the collector to emitter since IC = IB = 0 which indicates transistor is in off state that is a cut off region. But a small fraction of leakage current flows throw the transistor from collector to emitter i.e, I_{CEO}.

A transistor is said to be inactive state only when the base-emitter region is forward bias and collector-base region reverse bias. Hence there will be a flow of current IB in the base of transistor and flow of current IC through the collector to emitter of the transistor. When IB increases IC also increases.

A transistor is said to be in the quasi saturation stage if base-emitter and collector-base are connected in forwarding bias. A transistor is said to be in hard saturation if base-emitter and collector-base are connected in forwarding bias.

V-I Output Characteristics of a Power Transistor

The output characteristics can be calibrated graphically as shown below, where the x-axis represents VCE and the y-axis represents I_C

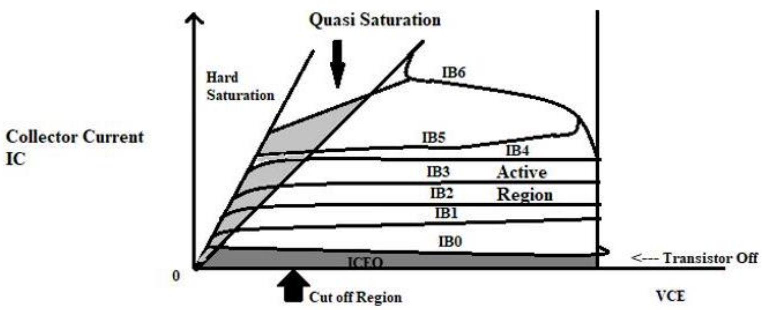


Fig:5.1:V-I Output Characteristics of a Power Transistor

The graph represents various regions like the cut-off region, active region, hard saturation region, quasi saturation region. For different values of VBE, there are different current values IB0, IB1, IB2, IB3, IB4, IB5, IB6. Whenever there is no current flow, it means the transistor is off. But few current flows which are ICEO. For increased value of IB = 0, 1,2, 3, 4, 5. Where IB0 is the minimum value and IB6 is the maximum value. When VCE increases ICE also increases slightly. Where $I_C = ßI_B$, hence the device is known as a current control device. Which means the device is in active region, which exists for a particular period. Once the I_C has reached to maximum the transistor switches to the saturation region.

Where it has two saturation regions quasi saturation region and hard saturation region. A transistor is said to be in a quasi saturation region if and only if the switching speed from on to off or off to on is fast. This type of saturation is observed in the medium-frequency application. Whereas in a hard saturation region the transistor requires a certain amount of time to switch from on to off or off to on state. This type of saturation is observed in the low-frequency applications.

Advantages

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

Disadvantages

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

Applications

- **Switch-mode power supplies (SMPS)**
- **Relays**
- **Power amplifiers**
- **DC to AC converters**
- **Power control circuits.**

Power MOSFET

A power MOSFET is a specific type of metal–oxide–semiconductor field-effect transistor (MOSFET) designed to handle significant power levels. ... The design of power MOSFETs was made possible by the evolution of MOSFET and CMOS technology, used for manufacturing integrated circuits since the 1960s. Power MOSFET is a type of MOSFET which is specially meant to handle high levels of power. These exhibit high switching speed and can work much better in comparison with other normal MOSFETs in the case of low voltage levels. However its operating principle is similar to that of any other general MOSFET. Power MOSFETs which are most widely used are n-channel Enhancement-mode or p-channel Enhancement-mode or n-channel Depletion-mode in nature. Further, there are a wide variety of power MOSFET structures like Vertical Diffused MOS (VDMOS) or Double-Diffused MOS or DMOS, UMOS or Trench-MOS, VMOS, etc. An n-substrate VDMOS made of n-substrate and an n-epitaxial layer into which p and n+ regions are embedded into using double diffusion process

Here the channel is formed in a p-type region when the gate-to-source voltage is made positive. Most importantly, here, the Source (S) terminal is placed over the Drain (D) terminal forming a vertical structure. As a result, in VDMOS the current flows beneath the gate area vertically between the source and the drain terminals through numerous n+ sources conducting in-parallel. As a result, the resistance offered by the device during its ON state $R_{DS(ON)}$ is much lower than that in the case of normal MOSFETs which enable them to handle high currents. This resistance of the device is seen to double as the current increments by about 6% . On the other hand $R_{DS(ON)}$ is highly influenced by the junction temperature T_J and is seen to be positive in nature.

Similar to this we can even have a p-substrate power MOSFET provided we replace n-type materials with p-type and then reverse the polarities of the voltages applied. However they exhibit a much higher $R_{DS(ON)}$ in comparison with n-substrate devices as they employ holes as their majority charge carriers instead of electrons. Nevertheless, these are preferred to be used as buck converters.

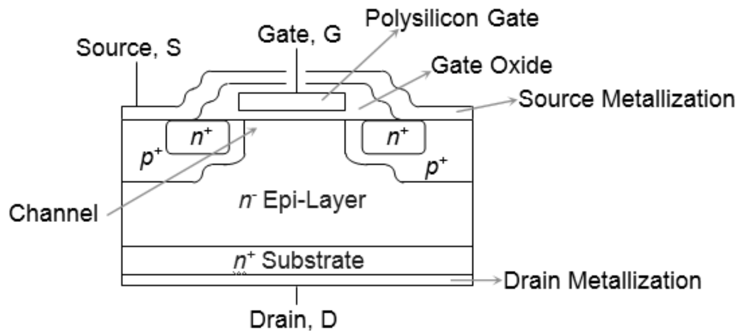


Fig:5.2:Schematic of n substrate power MOSFET

Although the structures of the normal MOSFETs and the power MOSFETs are seen to be different, the basic principle behind their working remains unaltered. That is, in both of them the formation of conduction channel is the same which is nothing but the suitable bias applied at the gate terminal resulting in an inversion layer. As a result, the nature of transfer characteristics and the output characteristics exhibited by either of them are almost identical to each other.

Further, it is to be noted that in the case of power MOSFETs which are based on vertical structure, the doping and the thickness of the epitaxial layer decide the voltage rating while the channel width decides its current rating. This is the reason because of which they can sustain high blocking voltage and high current, making them suitable for low power switching applications. However even lateral-structure based MOSFETs exist which behaves better in comparison with vertical-structure based designs especially in saturated operating region, enabling their use in high-end audio amplifiers. Another advantage of power MOSFET is the fact that they can be paralleled as their forward voltage drop increases with an increase in the temperature which in turn assures equal current distribution amongst all of its components. Power MOSFETs are extensively used as a part of power supplies, DC-DC converters and low-voltage motor controllers.

Power FET structure (DMOS and VMOS)

Power MOSFETS are designed to handle significant power levels. It's main advantage are its high commutation speed and good efficient at low levels. Power MOSFETS have different structures than lateral MOSFETS by having a vertical structure rather than a planar structure. The DMOS and VMOS both exhibit a vertical structure that will be discussed.

Typically used in:

- **Automobile Control Electronics**
- **Inkjet Print heads**
- **Power Supplies**

DMOS Structure

The DMOS device uses a double diffusion process. The p-substrate region and the n+ source contact are diffused through a common window defined by the edge of the gate. The p-substrate region is diffused deeper than the n+ source. The surface channel length is defined as the lateral diffusion distance between the p-substrate and the n+ source. Electrons enter the source terminal and flow laterally through the inversion layer under the gate to the n-drift region. The electrons then flow vertically through the n-drift region to the drain terminal. The convention current direction is from the drain to the source.

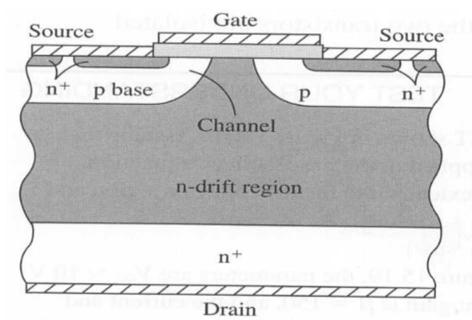


Fig:5.3: DMOS Structure

Most important characteristics are the breakdown voltage and on-resistance. DMOS is similar to a BJT, due to the high-voltage and high-frequency characteristics. A lightly doped drift region between the drain contact and the channel region helps to ensure a very high breakdown voltage. The n-drift region must be moderately doped so that the drain breakdown voltage is sufficiently large. The thickness of the n-drift region should be as thin as possible to minimize drain resistance.

VMOS:

VMOS - Vertical Metal Oxide Silicon. Gets its name from the V-shaped gate region. They have been established as a useful power MOSFET . VMOS FETs are used for a variety of applications where medium powers are required from power supply switching applications to medium power RF amplifiers

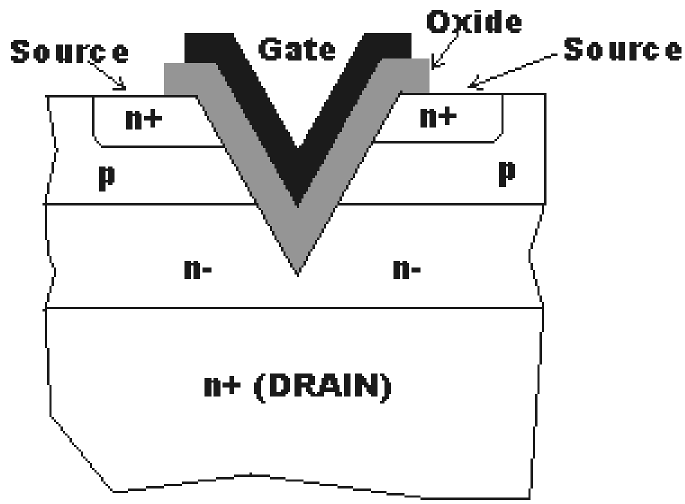


Fig:5.4: VMOS Structure

The biggest feature in the structure of the VMOS is the Shaped groove. It can be seen that the source is at the top of the device while the drain is at the bottom. So current flows vertically in the device instead of horizontally as in Standard FETS. V shaped gate increases the cross-sectional area of the source-drain path. This reduces the ON resistance of the device allowing it to handle much higher powers. The gate consists of a metallised area over the V groove and this controls the current flow in the P region.

The main drawback to the VMOS FET is that the structure is more complicated than the traditional FET and this makes it slightly more expensive. Power MOSFETS differ from lateral MOSFETS with the vertical structure of the DMOS and the VMOS. These are used in a variety of applications that desire high switching speeds and a variety of voltage levels. The doping and channel lengths contribute to the characteristics of each of these MOSFETS. The main advantages are the high commutation speed and its good efficiency at low voltages

Cathode Ray Oscilloscope (CRO)

The CRO stands for a cathode ray oscilloscope. It is typically divided into four sections which are display, vertical controllers, horizontal controllers, and Triggers. Most of the oscilloscopes are used the probes and they are used for the input of any instrument. We can analyze the waveform by plotting amplitude along with the x-axis and y-axis. The applications of CRO's mainly involve in the radio, TV receivers, also in laboratory work involving research and design. In modern electronics, the CRO plays an important role in the electronic circuits.

The cathode ray oscilloscope is an electronic test instrument, it is used to obtain waveforms when the different input signals are given. In the early days, it is called as an Oscillograph. The oscilloscope observes the changes in the electrical signals over time, thus

the voltage and time describe a shape and it is continuously graphed beside a scale. By seeing the waveform, we can analyze some properties like amplitude, frequency, rise time, distortion, time interval and etc.

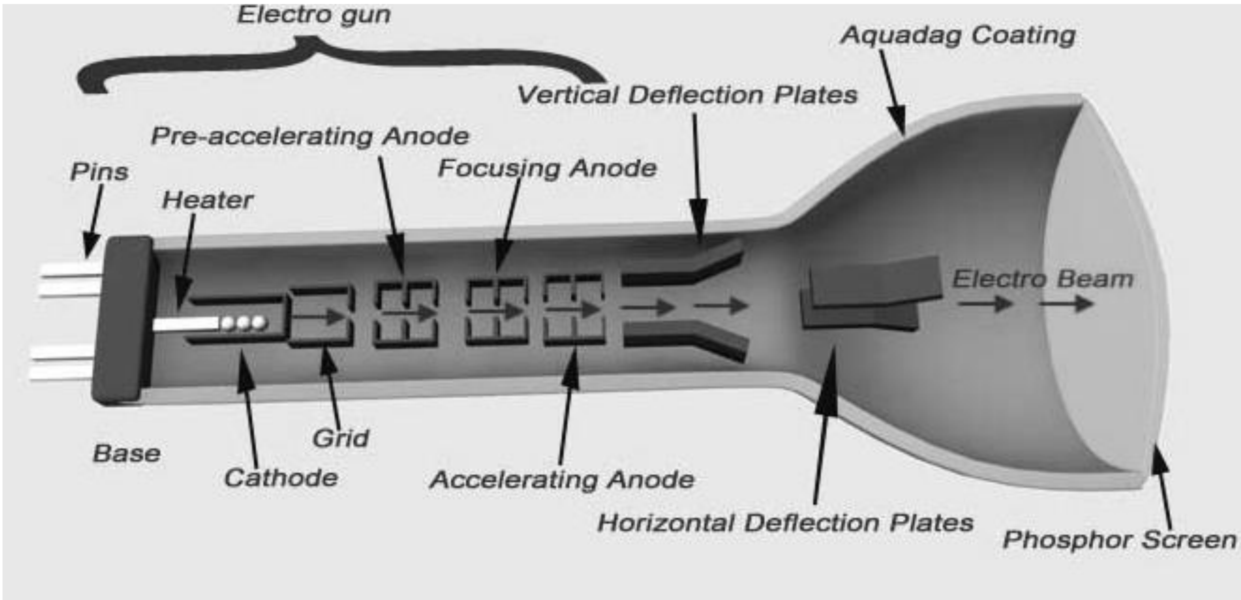


Fig:5.5: Internal structure of CRT

Block Diagram of CRO

The following block diagram shows the general purpose CRO contraction. The CRO recruit the cathode ray tube and acts as a heat of the oscilloscope. In an oscilloscope, the CRT produces the electron beam which is accelerated to a high velocity and brings to the focal point on a fluorescent screen. Thus, the screen produces a visible spot where the electron beam strikes with it. By detecting the beam above the screen in reply to the electrical signal, the electrons can act as an electrical pencil of light which produces a light where it strikes

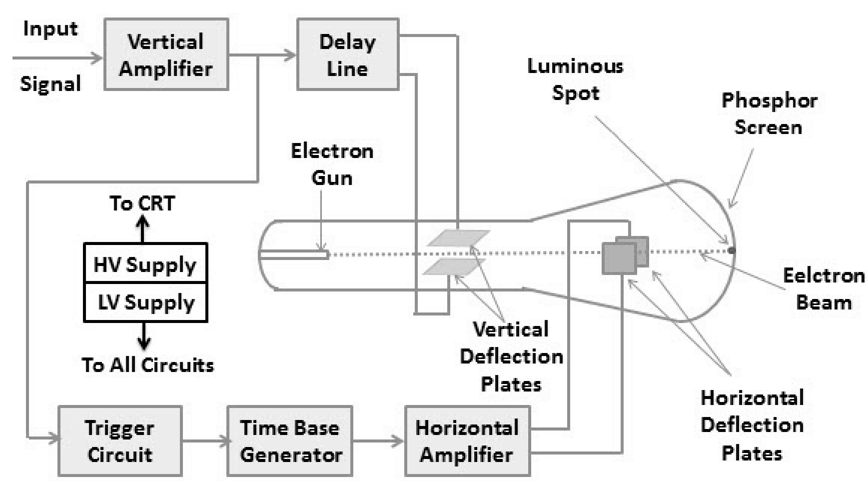


Fig:5.6: Block Diagram of CRO

To complete this task we need various electrical signals and voltages. This provides the power supply circuit of the oscilloscope. Here we will use high voltage and low voltage. The low voltage is used for the heater of the electron gun to generate the electron beam. The high voltage is required for the cathode ray tube to speed up the beam. The normal voltage supply is necessary for other control units of the oscilloscope. The horizontal and vertical plates are placed between the electron gun and the screen, thus it can detect the beam according to the input signal. Just before detecting the electron beam on the screen in the horizontal direction which is in X-axis a constant time-dependent rate, a time base generator is given by the oscillator. The signals are passed from the vertical deflection plate through the vertical amplifier. Thus, it can amplify the signal to a level will be provided the deflection of the electron beam. If the electron beam is detected in the X-axis and the Y- axis a trigger circuit is given for the synchronizing these two types detections. Hence the horizontal deflection starts at the same point of the input signal.

Working of CRO

Vertical Deflection System

The main function of this amplifier is to amplify the weak signal so that the amplified signal can produce the desired signal. To examine the input signals are penetrated to the vertical deflection plates through the input attenuator and number of amplifier stages.

Horizontal Deflection System

The vertical and horizontal system consists of horizontal amplifiers to amplify the weak input signals, but it is different to the vertical deflection system. The horizontal deflection plates are penetrated by a sweep voltage that gives a time base. By seeing the circuit diagram the sawtooth sweep generator is triggered by the synchronizing amplifier while the sweep selector switches in the internal position. So the trigger saw tooth generator gives the input to the horizontal amplifier by following the mechanism. Here we will discuss the four types of sweeps.

Recurrent Sweep

As the name, itself says that the saw tooth is respective that is a new sweep is started immodestly at the end of the previous sweep.

Triggered Sweep

Sometimes the waveform should be observed that it may not be predicted, thus the desired that the sweep circuit remains inoperative and the sweep should be initiated by the waveform under the examination. In these cases, we will use the triggered sweep.

Driven Sweep

In general, the drive sweep is used when the sweep is a free running but it is a triggered by the signal under the test.

Non-Saw Tooth Sweep

This sweep is used to find the difference between the two voltages. By using the non-sawtooth sweep we can compare the frequency of the input voltages.

Synchronization

The synchronization is done to produce the stationary pattern. The synchronization is between the sweep and the signal should measure. There are some sources of synchronization which can be selected by the synchronization selector. Which are discussed below

Internal

In this the signal is measured by the vertical amplifier and the trigger is abstained by the signal.

External

In the external trigger, the external trigger should be present.

Line

The line trigger is produced by the power supply.

Intensity Modulation

This modulation is produced by inserting the signal between the ground and cathode. This modulation causes by brightening the display.

Positioning Control

By applying the small independent internal direct voltage source to the detecting plates through the potentiometer the position can be controlled and also we can control the position of the signal.

Intensity Control

The intensity has a difference by changing the grid potential with respect to the cathode.

Applications of CRO

- **Voltage measurement**
- **Current measurement**
- **Examination of waveform**
- **Measurement of phase and frequency**

Uses of CRO

- **It can display different types of waveforms**
- **It can measure short time interval**
- **In voltmeter, it can measure potential difference**

Laser Diode

A Laser Diode is a semiconductor device similar to a light-emitting diode (LED). It uses p-n junction to emit coherent light in which all the waves are at the same frequency and phase. This coherent light is produced by the laser diode using a process termed as "Light Amplification by Stimulated Emission of Radiation", which is abbreviated as LASER. And since a p-n junction is used to produce laser light, this device is named as a laser diode.

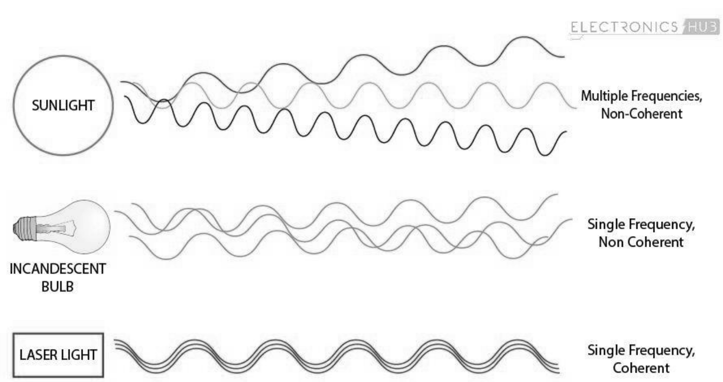


Fig:5.7: Laser light is different from other types of light

The light from sunlight or from most of the artificial light sources contains waves of multiple wavelengths and they are out of phase with each other. The light waves from monochromatic light sources like incandescent bulb also are not in phase with each other. In contrast to the previous light sources, laser diodes produce a narrow beam of laser light

in which all the light waves have similar wavelengths and they travel together with their peaks lined up. This is why laser beams are very bright, and can be focused over a very tiny spot. Of all the devices that produce laser light, laser diodes or semiconductor lasers are the most efficient and they come in smaller packages. So they are widely used in various devices like laser printers, barcode readers, security systems, Autonomous vehicles (LIDAR), Fiber optic communications etc.

Working of LASER diode

The working of a laser diode takes place in three main steps:

Energy Absorption

The laser diode consists of a p-n junction where holes and electrons exist. (Here, a hole means the absence of an electron). When a certain voltage is applied at the p-n junction, the electrons absorb energy and they transition to a higher energy level. Holes are formed at the original position of the excited electron. The electrons stay in this excited state without recombining with holes for a very small duration of time, termed as "recombination time" or "upper-state lifetime". The recombination time is about a nanosecond for most laser diodes.

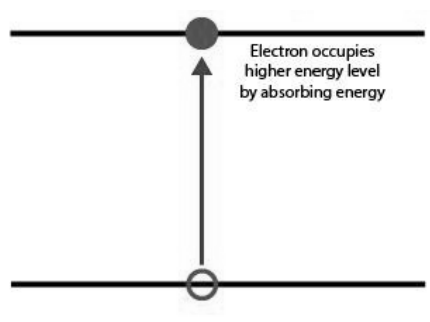


Fig:5.8: Energy Absorption

Spontaneous Emission

After the upper-state lifetime of excited electrons, they recombine with holes. As the electrons fall from higher energy level to a lower energy level, the difference in energy is converted into photons or electromagnetic radiation. This same process is used to produce light in LEDs. The energy of the emitted photon is given by the difference between the two energy levels.

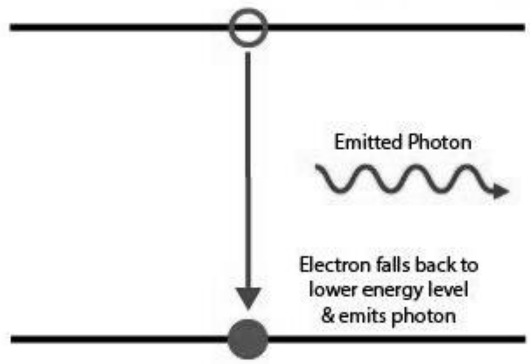


Fig:5.9: Spontaneous Emission

Stimulated Emission

We need more coherent photons from the laser diode than the ones emitted through the process of spontaneous emission. A partially reflecting mirror is used on either side of the diode so that the photons released from spontaneous emission are trapped in the p-n junction until their concentration reaches a threshold value. These trapped photons stimulate the excited electrons to recombine with holes even before their recombination time. This results in the release of more photons that are in exact phase with the initial photons and so the output gets amplified. Once the photon concentration goes above a threshold, they escape from the partially reflecting mirrors, resulting in a bright monochromatic coherent light.

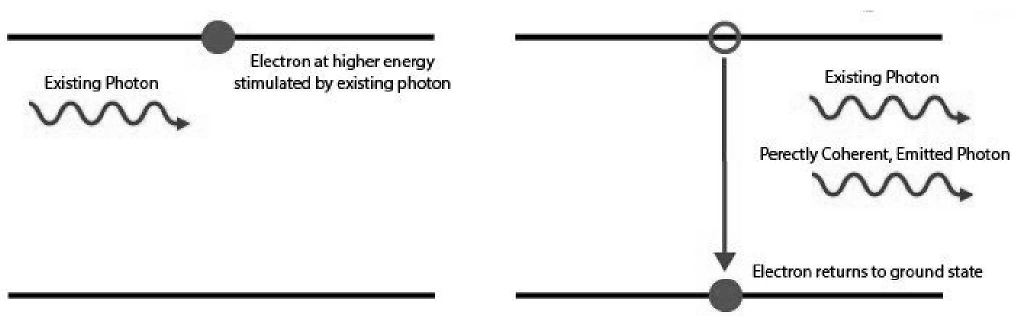


Fig:5.10: Stimulated Emission

Construction of a Laser Diode

A simple semiconductor laser diode is made up of the following parts in order:

- **Metal Contact**
- **P-type Material**
- **Active/Intrinsic Region (N-type Material)**
- **N-type Material**

- **Metal Contact**

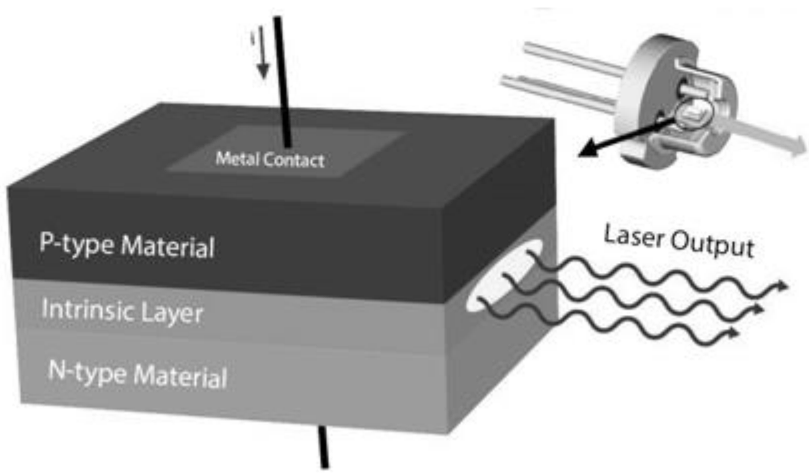


Fig:5.10: Construction of a Laser Diode

The input terminals are connected to a metal plates which are sandwiched to the n-type and p-type layers. This type of laser diode is also called as a “Homojunction Laser Diode”. The intrinsic region between the p-type and n-type material is used to increase the volume of active region, so that more number of holes and electrons can accumulate at the junction. This allows more number of electrons to recombine with holes at any instant of time, resulting in better output power. The laser light is emitted from the elliptical region. This beam from the laser diode can be further focused using an optical lens. This entire PIN diode (P-type, Intrinsic, N-Type) arrangement is enclosed normally in a metal casing.

Laser Diode P-I Characteristics

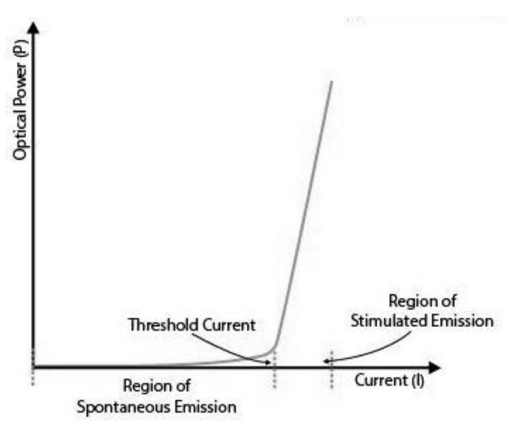


Fig:5.11: P-I Characteristics of Laser Diode

The above diagram is a graphical plot between output optical power on y-axis and the current input to the laser diode on x-axis.

As we increase the current flow to the laser diode, the optical power of output light gradually increases up to a certain threshold. Until this point, most of the light emitted is due to spontaneous emission. Above this threshold current, the process of stimulated emission increases. This causes the power of output light to increase a lot even for smaller increases in input current. The output optical power also depends on temperature and it reduces with decrease in temperature.

Applications of a Laser Diode

Laser Diode modules are used in all major areas of electronics ranging from

- Consumer Electronics: CD/DVD players, Laser printers, Fiber Optic Communication, Barcode Readers etc.
- Medical Machines: Laser diodes are used in machines used to remove unwanted tissues, eliminating cancer cells, non-invasive and cataract surgeries etc.
- Autonomous Vehicles: Laser diode technology is used in making LIDAR systems implemented for autonomous driving
- Scientific Instrumentation: Lasers are used in devices used for remote contactless measurements, spectrometry, range finders etc.
- Industrial Applications: Laser Diodes are used as a source of high intensity laser beam for precise cutting of materials. They are also used in 3D printing to soften the substrate.

Operation of LCDs

The principle behind the LCD's is that when an electrical current is applied to the liquid crystal molecule, the molecule tends to untwist. This causes the angle of light which is passing through the molecule of the polarized glass and also cause a change in the angle of the top polarizing filter. As a result, a little light is allowed to pass the polarized glass through a particular area of the LCD. Thus that particular area will become dark compared to others. The LCD works on the principle of blocking light. While constructing the LCD's, a reflected mirror is arranged at the back. An electrode plane is made of indium-tin-oxide which is kept on top and a polarized glass with a polarizing film is also added on the bottom of the device. The complete region of the LCD has to be enclosed by a common electrode and above it should be the liquid crystal matter.

Next comes the second piece of glass with an electrode in the form of the rectangle on the bottom and, on top, another polarizing film. It must be considered that both the pieces are kept at the right angles. When there is no current, the light passes through the front of the LCD it will be reflected by the mirror and bounced back. As the electrode is connected to a battery the current from it will cause the liquid crystals between the common-plane electrode and the electrode shaped like a rectangle to untwist. Thus the light is blocked from passing through. That particular rectangular area appears blank.

Advantages of an LCD's:

- **LCD's consumes less amount of power compared to CRT and LED**
- **LCD's are consist of some microwatts for display in comparison to some mill watts for LED's**
- **LCDs are of low cost**
- **Provides excellent contrast**
- **LCD's are thinner and lighter when compared to cathode-ray tube and LED**

Disadvantages of an LCD's:

- **Require additional light sources**
- **Range of temperature is limited for operation**
- **Low reliability**
- **Speed is very low**

Applications of Liquid Crystal Display

Liquid crystal technology has major applications in the field of science and engineering as well on electronic devices.

- **Liquid crystal thermometer**
- **Optical imaging**
- **The liquid crystal display technology is also applicable in the visualization of the radio frequency waves in the waveguide**
- **Used in the medical applications**
- **LCD's need an AC drive**

LED (Light Emitting Diode) :

LED (Light Emitting Diode) is an optoelectronic device which works on the principle of electro-luminance. Electro-luminance is the property of the material to convert electrical energy into light energy and later it radiates this light energy. In the same way, the semiconductor in LED emits light under the influence of electric field.

Construction of LED

The semiconductor material used in LED is Gallium Arsenide (GaAs), Gallium Phosphide (GaP) or Gallium Arsenide Phosphide (GaAsP). Any of the above-mentioned compounds can be used for the construction of LED, but the colour of radiated light changes with the change in material. Below are some of the material and their respective colour of light which they emit.

Working of LED

The electrons are majority carriers in N-type and holes are majority carriers in P-type. The electrons of N-type are in the conduction band and holes of P-type are in the

valence band. The energy level of the Conduction band is higher than the energy level of the Valence band. Thus, if electrons tend to recombine with holes they have to lose some part of the energy to fall in lower energy band. The electrons can lose their energy either in the form of heat or light. The electrons in Silicon and Germanium lose their energy in the form of heat. Thus, they are not used for LEDs as we want semiconductor in which electrons lose their energy in the form of light.

Emission of Photons

Thus, semiconductor compounds such as Gallium Phosphide (Gap), Gallium Arsenide (GaAs), Gallium Arsenide Phosphide (GaAsP) etc. emit light when electrons-holes recombine. The electrons in these compounds lose their energy by emission of photons. If the semiconductor material is translucent, the light will be emitted from the junction as junction acts as the source of light. LED is operated in forward biased mode only. If it will operate in reverse biased it will get damage as it cannot with stand reverse voltage.

Volt-Ampere Characteristics of LEDs

The characteristics curve of the LED shows that the forward bias of 1 V is sufficient to increase the current exponentially.

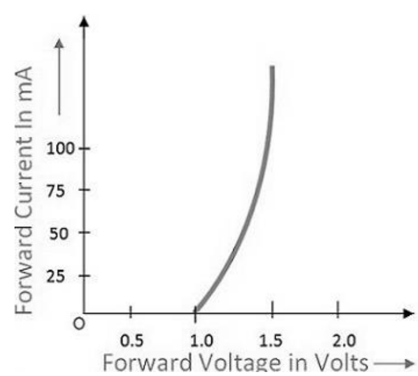


Fig:5.12: Volt-Ampere Characteristics of LEDs

The output characteristics curve shows that radiant power of LED is directly proportional the forward current in LED.

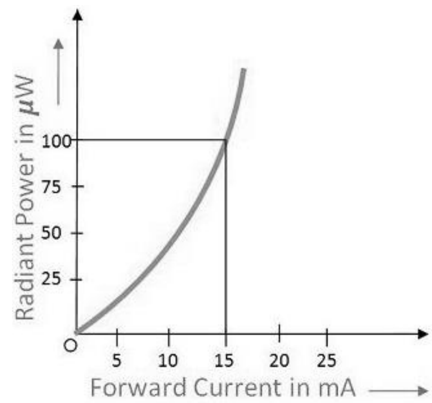


Fig:5.13: Output characteristics

Optocoupler

An Optocoupler, is an electronic components that interconnects two separate electrical circuits by means of a light sensitive optical interface.

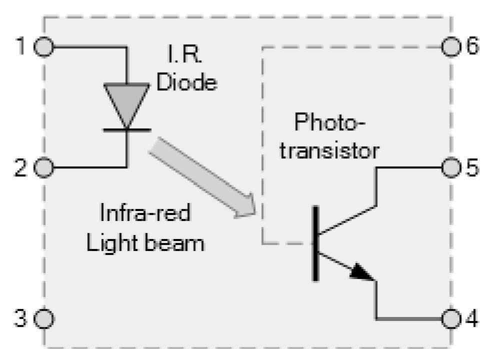


Fig:5.14: Structure of optocoupler

Assume a photo-transistor device as shown. Current from the source signal passes through the input LED which emits an infra-red light whose intensity is proportional to the electrical signal. This emitted light falls upon the base of the photo-transistor, causing it to switch-ON and conduct in a similar way to a normal bipolar transistor. The base connection of the photo-transistor can be left open (unconnected) for maximum sensitivity to the LEDs infra-red light energy or connected to ground via a suitable external high value resistor to control the switching sensitivity making it more stable and resistant to false triggering by external electrical noise or voltage transients. When the current flowing through the LED is interrupted, the infra-red emitted light is cut-off, causing the photo-transistor to cease conducting. The photo-transistor can be used to switch current in the output circuit. The spectral response of the LED and the photo-sensitive device are closely matched being separated by a transparent medium such as glass, plastic or air. Since there is no direct electrical connection between the input and output of an opto coupler, electrical isolation up to 10kV is achieved.

Solar cell

A solar cell (also known as a photovoltaic cell or PV cell) is defined as an electrical device that converts light energy into electrical energy through the photovoltaic effect. A solar cell is basically a p-n junction diode. Solar cells are a form of photoelectric cell, defined as a device whose electrical characteristics – such as current, voltage, or resistance vary when exposed to light. Individual solar cells can be combined to form modules commonly known as solar panels. The common single junction silicon solar cell can produce a maximum open-circuit voltage of approximately 0.5 to 0.6 volts. By itself this isn't much – but remember these solar cells are tiny. When combined into a large solar panel, considerable amounts of renewable energy can be generated.

Construction of Solar Cell

A solar cell is basically a junction diode, although its construction it is little bit different from conventional p-n junction diodes. A very thin layer of p-type semiconductor is grown on a relatively thicker n-type semiconductor. We then apply a few finer electrodes on the top of the p-type semiconductor layer. These electrodes do not obstruct light to reach the thin p-type layer. Just below the p-type layer there is a p-n junction. We also provide a current collecting electrode at the bottom of the n-type layer. We encapsulate the entire assembly by thin glass to protect the solar cell **from any mechanical shock**.

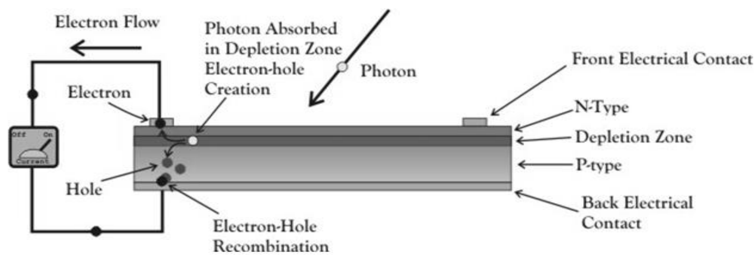


Fig:5.15: Construction of Solar Cell

Working Principle of Solar Cell

When light reaches the p-n junction, the light photons can easily enter in the junction, through very thin p-type layer. The light energy, in the form of photons, supplies sufficient energy to the junction to create a number of electron-hole pairs. The incident light breaks the thermal equilibrium condition of the junction. The free electrons in the depletion region can quickly come to the n-type side of the junction. Similarly, the holes in the depletion can quickly come to the p-type side of the junction. Once, the newly created free electrons come to the n-type side, cannot further cross the junction because of barrier potential of the junction. Similarly, the newly created holes once come to the p-type side cannot further cross the junction became of same barrier potential of the junction. As the concentration of electrons becomes higher in one side, i.e. n-type side of the junction and concentration of holes becomes more in another side, i.e. the p-type side of the junction, the p-n junction will behave like a small battery cell. A voltage is set up which is known as

photo voltage. If we connect a small load across the junction, there will be a tiny current flowing through it.

Advantages of Solar Cell

1. **No pollution associated with it.**
2. **It must last for a long time.**
3. **No maintenance cost.**

Disadvantages of Solar Cell

1. **It has high cost of installation.**
2. **It has low efficiency.**
3. **During cloudy day, the energy cannot be produced and also at night we will not get solar energy.**

Uses of Solar Generation Systems

1. **It may be used to charge batteries.**
2. **Used in light meters.**
3. **It is used to power calculators and wrist watches.**
4. **It can be used in spacecraft to provide electrical energy**.

Charge Coupled Device (CCD)

Charge Coupled Devices can be defined in different ways according to the application for which they are used or based on the design of the device.

It is a device used for the movement of electrical charge within it for the charge manipulation, which is done by changing the signals through stages within the device one at a time. It can be treated as CCD sensor, which is used in the digital and video cameras for taking images and recording videos through photoelectric effect. It is used for converting the captured light into digital data, which is recorded by the camera. It can be defined as a light-sensitive integrated circuit imprinted on a silicon surface to form light-sensitive elements called pixels, and each pixel is converted into an electrical charge

Charge Coupled Device's Working Principle

The silicon epitaxial layer acting as a photoactive region and a shift- register-transmission region are used for capturing images using a CCD. Through the lens image is projected onto the photo active region consisting of capacitor array. Thus, the electric charge proportional to the light intensity of the image pixel color in the color spectrum at that location is accumulated at each capacitor. If the image gets detected by this capacitor

array, then the electrical charge accumulated in each capacitor is transferred to its neighbor capacitor by performing as a shift register controlled by the control circuit.

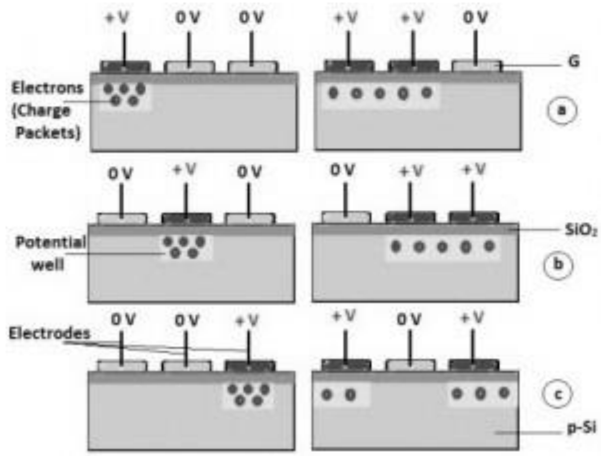


Fig:5.16: Working of CCD

In the above figure, from a, b and c, the transfer of charge packets is shown according to the voltage applied to the gate terminals. At last, in the array electrical charge of last capacitor is transferred into the charge amplifier in which the electric charge is converted into a voltage. Thus, from the continuous operation of these tasks, entire charges of the capacitor array in the semiconductor are converted into a sequence of voltages. This sequence of voltages is sampled, digitized and then stored in memory in case of digital devices such as digital cameras. In case of analog devices such as analog video cameras, this sequence of voltages is fed to a low-pass filter to produce a continuous analog signal, and then the signal is processed for transmission, recording and for other purposes.

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