Subject Name: **Electronic Devices & Circuits**

Subject Code: **EC-3004**

Semester: **3rd**

UNIT I

Syllabus:

Introduction to semiconductor physics: insulator, conductor, semiconductor and semiconductor types. Drift and diffusion carries, Hall Effects. Review of PN junction diode: PN junction diode in forward and reverse bias, temperature dependence of V-I characteristics, diode resistances, diode junction capacitance. Types of diodes: Zener Diode, Varactor Diode, Tunnel Diode, PIN Diode, Schottky Diode, LED and Photo Diodes, Switching characteristics of diode.

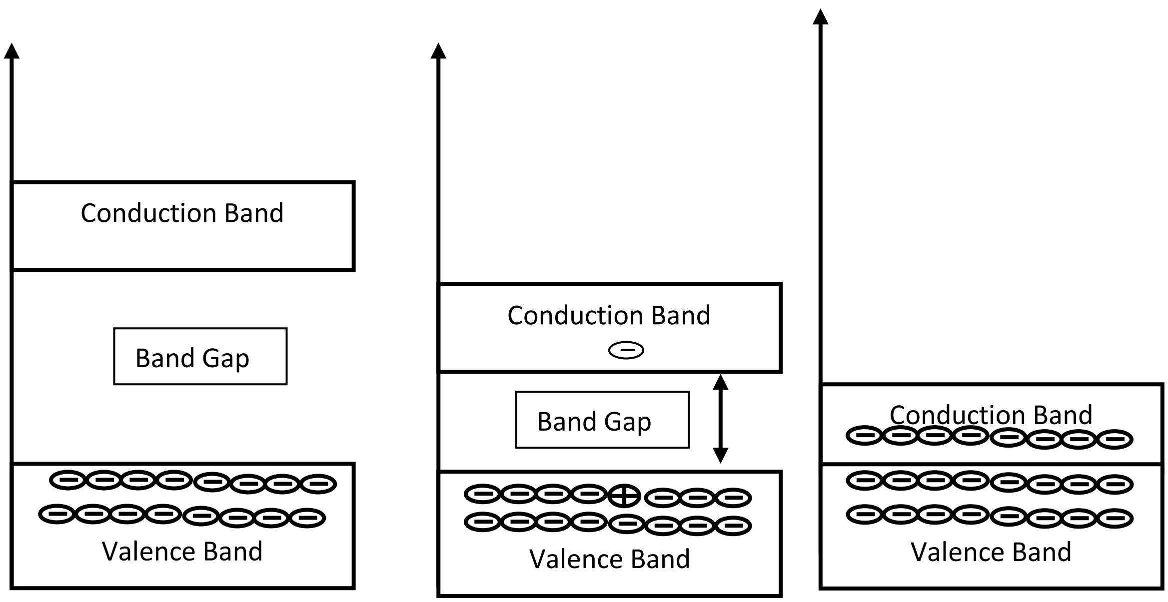
Insulator: Through these materials electricity cannot pass is called insulators. Plastic, glass, wood etc are the examples of insulators. The valence band of those materials remains full of electrons. The conduction band of those materials remains empty. The forbidden energy gap between the conduction band and the valence band is widest. The difference is more than 10ev. Crossing the forbidden energy gap from valence band to conduction band large amount of energy is needed.

In a diamond crystal the value of forbidden energy is as high as 7ev and so it is impossible cross forbidden gap to conduction band even at high temperature. So, the conduction band of diamond remains empty, as there is no flow of current. Hence diamond is a very good insulator.

Conductors: In figure b shows the energy band of good conductor or metal. The valence band and the conduction band is attached here on overlap each other. There is no forbidden energy gap here so E_g=0. At absolute zero temperature large number of electrons remains in the conduction band. The resistance of conductor is very low; large number charge carriers are available here. So, the electricity can pass easily through the conductors.

Semiconductors: Semiconductors are those materials whose electrical conductivity is between conductors and insulators. The forbidden energy gap of a semiconductor is nearly same as insulator. The energy gap is narrower. The value of E_g =1.1eV for silicon crystal and E_g =0.7eV for germanium at ok. It can easily overcome due to thermal agitation or light. A semiconductor remains partially full valence band and partially full conduction band at the room temperature. The conduction band remains full empty of a semiconductor where the valence band remains full of electrons at absolute zero temperature. So, silicon and germanium are insulators at absolute zero temperature. On the other hand with the

increasing of temperature the electrical conductivity of semiconductors increases.



Insulator **Semiconductor** **Conductor**

Types of Semiconductor:

Intrinsic Semiconductor: - A semiconductor material in its purest form is known as an intrinsic semiconductor. An intrinsic semiconductor behaves as an insulator at 0 K but acts as a conductor at 300 K (room temperature). At room temperatures due to the thermal generation of electron-hole pairs, free electrons & holes are generated in equal numbers, these mobile charges help in the conduction of current in an intrinsic semiconductor. Since electron-hole pairs that are responsible for conduction of current in an intrinsic semiconductor are internal to the semiconductor crystal, the material is known as an intrinsic semiconductor.

Free Electrons or Conduction Electrons: - When external energy is supplied to a

Semiconductor crystals in the form of light or heat (increase in temperature), some covalent bonds breaks and produce free electrons. Every free electron has an associated vacant site (hole) in the covalent bond .These free electrons are not under the control of any of the nuclei within the crystal. Since free electrons take part in the conduction of current, they are also known as conduction electrons. Conduction electrons or free electrons have energy levels much higher than valence electrons and take part in the conduction of current in a semiconductor.

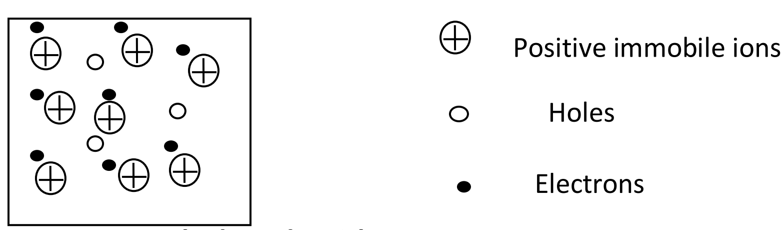
Valence Electrons or Bound Electrons: - The outer most orbit electrons or valence electrons are shared by the neighboring semiconductor atoms to form covalent bonds in a crystal. A valence electron is always associated with particular nuclei and is under its control, hence a valence electron is also known as a bound electron. A valence electron by itself cannot take part in the conduction of current. A valence electron will take part in the conduction of current only when there is hole movement, in other words hole movement is actually the movement of valence electrons in the valence band. At 0 K all the electrons in a Silicon crystal exist as valence electrons (ie. there are no free electrons or holes) hence there is no current conduction & Silicon behaves as an insulator.

Doping: - The process of adding a calculated quantity ($1:10^8$) of trivalent or pentavalent atoms to an intrinsic semiconductor is known as doping. Doping helps in generating a single type of charge carrier (either free electrons or holes). Doping thus increases the conductivity of a semiconductor at room temperatures.

Extrinsic Semiconductor: - An extrinsic semiconductor is obtained by doping an intrinsic

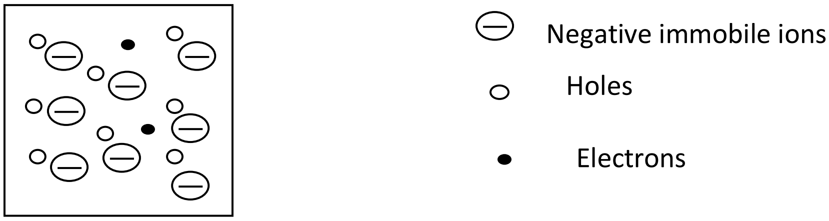
Semiconductor with trivalent or pentavalent impurity atoms. Depending upon the valency of the impurity atoms added we obtain either p-type or n-type extrinsic semiconductor.

N –Type Extrinsic Semiconductor



Semiconductor material doped with donors. Material has high concentration of free electrons. Concentration of holes in n-type material is very low. It contains POSITIVELY charged donors (immovable) and NEGATIVELY charged free electrons. It contains POSITIVELY charged donors (immovable) and NEGATIVELY charged free electrons.

P –Type Extrinsic Semiconductor



Semiconductor material doped with acceptors. Material has high hole concentration. Concentration of free electrons in p-type material is very low. It contains NEGATIVELY charged acceptors (immovable) and POSITIVELY charged holes (free). It contains NEGATIVELY charged acceptors (immovable) and POSITIVELY charged holes (free).

Drift current

In a homogeneously doped semiconductor or a semiconductor with a constant carrier density, applying an electric field will cause drift currents to flow. Drift current can be carried by both electrons and holes.

Drift current in a semiconductor is given by:

$$I_{tot} = \sigma_{tot} AE = eA(n\mu_n + p\mu_p)E$$

With A the cross sectional area perpendicular to the current flow, E is the applied electric field. Remember that the electric field can also be internal to the device structure.

Diffusion current

When carrier gradients exist in a semiconductor, diffusion currents will occur. Hole density gradients cause hole diffusion currents, electron density gradients cause electron diffusion currents and gradients in both carrier types will cause diffusion of both, creating a total diffusion current of:

$$I_{tot} = eA\left(D_n \frac{dn}{dx} - D_p \frac{dp}{dx} \right)$$

With $D_{n,p}$ the diffusion constant of electrons respectively holes, x is the direction of carrier propagation. The Einstein equation gives the relationship between the diffusion constant and the mobility of the carrier:

$$\frac{D}{\mu} = \frac{kT}{e}$$

with, k the Boltzman constant, T the temperature in Kelvin.

In the general case where both concentration gradients and electric fields are present the total current is the sum of both drift and diffusion currents:

$$I_{tot} = eA\left(n\mu_n E + p\mu_p E + D_n \frac{dn}{dx} - D_p \frac{dp}{dx} \right)$$

This equation is normally referred to as the drift-diffusion equation of carriers and is the basic equation that describes carrier movement in semiconductor devices.

Note that the direction of the electron particle flux is opposite to the current flow. Particle flux is strictly governed by electrostatics, the current is dependent on the sign of the charge q=±e.

The third important basic equation in semiconductor devices is the Poisson equation

$$\frac{d^2V}{dx^2} = -\frac{\rho(x)}{\varepsilon} = -\frac{e}{\varepsilon}\left(p - n + N_D^+ - N_A^-\right)$$

With V the electrostatic potential, the charge density is a function of x ; p & n the free hole, resp. electron density which are both a function of x as well as of V and $N_D^+ \,\&\, N_A^-$ the concentration of ionized doping atoms which are a function of x.

PN Diode:

Current will flow through a material provided that there are charge carriers free to move and an electric field to move them. Conductors (such as copper) have lots of charge carriers (electrons) ready to move in response to the slightest electric field. Insulators (such as diamond) possess very few free charge carriers – all the electrons are tightly bound to the crystal lattice, so that, even in the presence of a strong electric field, no current flows. Semiconductors (such as silicon and germanium) are somewhere in between. The conductivity of a semiconductor can be enhanced through doping, the deliberate inclusion of impurities within the semiconductor lattice.

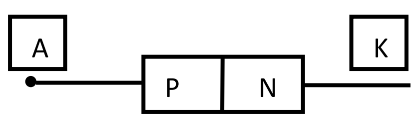
Silicon, for example, has four valence electrons, which are used to make covalent bonds with neighboring silicon atoms. Phosphorus has five valence electrons, and boron has three. In a silicon crystal, if a silicon atom is replaced with a 'donor' material, such as phosphorus, an extra valence electron becomes available that is loosely bound to the lattice. If an 'acceptor' material such as boron is substituted for silicon, a 'hole' appears in the electron structure of the lattice. Doping silicon with a donor material creates an 'N-type' semiconductor, whereas doping with an acceptor creates a 'P-type' semiconductor. (Note that, despite their names, these doped semiconductors are electrically neutral: the 'extra' electrons in N-type material are compensated for by the additional protons in the atomic nuclei of the donors, while the 'missing' electrons in P-type are compensated for by the missing protons in the acceptor nuclei.)

The 'extra' electrons within N-type material can move under the influence of an electric field. Thus, the dominant charge carriers are electrons; i.e., N-type material has negative charge carriers.

For P-type material, electrons from neighboring atoms can jump into the holes, moving the holes from one place to another. The holes can migrate in the direction of an electric field. The charge motion is thus due to the motion of the holes, i.e., P-type material has positive charge carriers.

If a junction between P-type and N-type semiconductor material is created within a single crystal, in such a way that the crystalline structure is preserved across the junction, the result is a junction diode. Electrons from the N-region migrate across the junction into the P-region, filling holes as they go. This creates a net charge build-up around the junction positive in the N-region and negative in the P-region leading to an internal electric field as shown. Once the holes are filled, the junction region becomes devoid of charge carriers and thus acts as an insulator, preventing further current flow.

If an external field is applied in the same direction as the internal field, the 'depletion region' (region around the junction devoid of charge carriers) increases in size, so current does not flow. On the other hand, if an external field is applied opposite to the internal field, free charge carriers flow toward the junction. Electrons flow into the N-type material from the metal contact (see Fig. below). New holes are created within the P-material as electrons jump from the semiconductor to the metal contacts. At the junction, the holes from the P-type material meet electrons from the N-type material and combine. A PN junction thus allows current to flow easily in one direction but blocks current flow in the reverse direction.

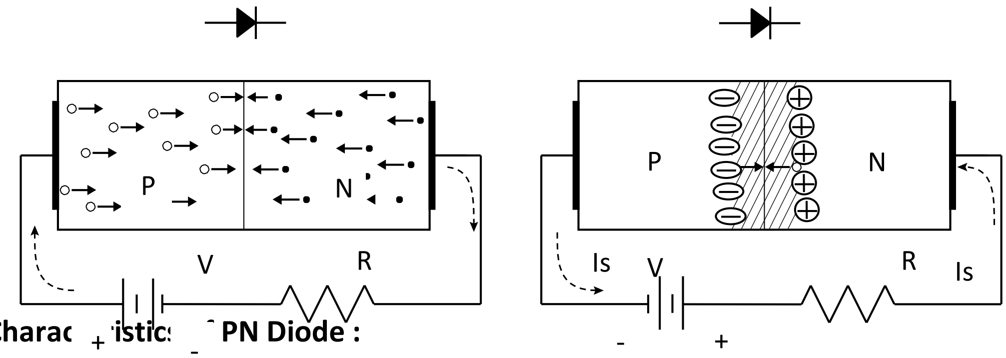


For such a diode the current I flowing through the device is given approximately by

$$I = I_S(e^{eV/nkT} - 1)$$

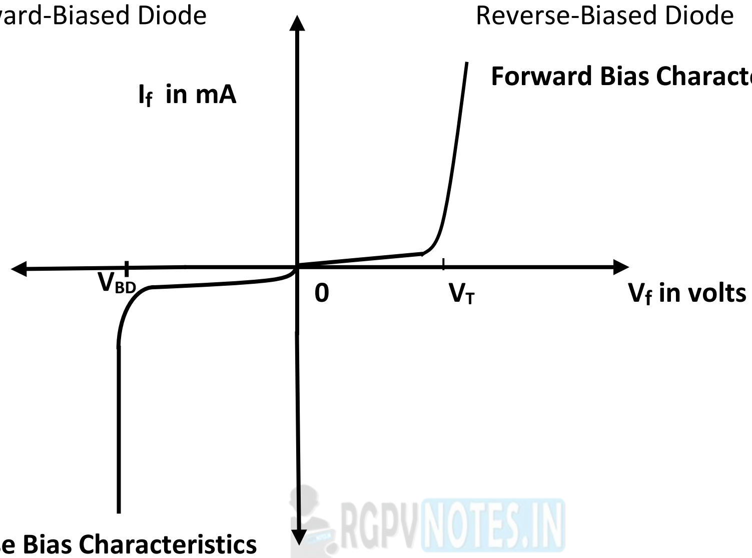
where I_S is the 'reverse saturation current', e is the electron charge, V is the voltage across the junction, n is an empirical constant between 1 and 2, k is Boltzmann's constant, and T is the junction temperature in kelvin.

VI Characteristics of PN Diode :



Forward-Biased Diode

Reverse-Biased Diode



V-I Characteristics of PN diode

When the P-type material is at a more positive voltage than the N-type material, the diode is said to be 'forward-biased'; this corresponds to V > 0 in Fig. When the P-type material is more negative than the N-type material, the diode is said to be 'reverse-biased'; this corresponds to V < 0 in Fig.

Temperature dependence of V-I characteristics:

PN junction diode parameters like reverse saturation current, bias current, reverse breakdown voltage and barrier voltage are dependent on temperature.

Mathematically diode current is given by

$$I = I_S(e^{eV/nkT} - 1)$$

Hence from equation we conclude that the current should decrease with increase in temperature but exactly opposite occurs there are two reasons:

Rise in temperature generates more electron-hole pair thus conductivity increases and thus increases in current

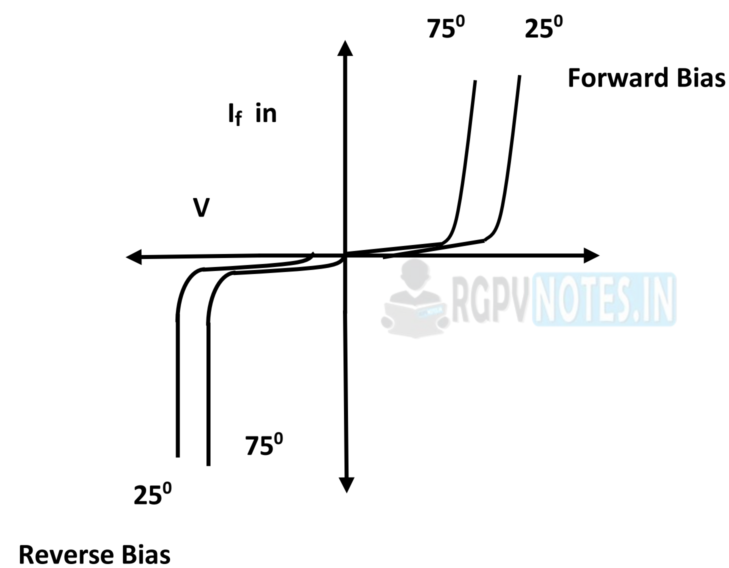
Increase in reverse saturation current with temperature offsets the effect of rise in temperature

Reverse saturation current (IS) of diode increases with increase in the temperature the rise is 7%/ºC for both germanium and silicon and approximately doubles for every 10ºC rise in temperature.

Thus if we kept the voltage constant, as we increase temperature the current increases.

Barrier voltage is also dependent on temperature it decreases by 2mV/ºC for germanium and silicon.

Reverse breakdown voltage (VR) also increases as we increase the temperature.



V-I Characteristics of PN

Diode Resistance:

A p-n junction diode allows electric current in one direction and blocks electric current in another direction. It allows electric current when it is forward biased and blocks electric current when it is reverse biased. However, no diode allows electric current completely even in forward biased condition.

The depletion region present in a diode acts like barrier to electric current. Hence, it offers resistance to the electric current. Also, the atoms present in the diode provide some resistance to the electric current.

When charge carriers (free electrons and holes) flowing through the diode collides with atoms, they lose energy in the form of heat. Thus, depletion region and atoms offer resistance to the electric current.

When forward biased voltage is applied to the p-n junction diode, the width of depletion region decreases. However, the depletion region cannot be completely vanished. There exists a thin depletion region or depletion layer in the forward biased diode. Therefore, a thin depletion region and atoms in the diode offer some resistance to electric current. This resistance is called forward resistance.

When the diode is reverse biased, the width of depletion region increases. As a result, a large number of charge carriers (free electrons and holes) flowing through the diode will be blocked by the depletion region.

In a reverse biased diode, only a small amount of electric current flows. The minority carriers present in the diode carry this electric current. Thus, reverse biased diode offer large resistance to the electric current. This resistance is called reverse resistance.

The two types of resistance takes place in the p-n junction diode are:

1. Forward resistance
2. Reverse resistance

Forward resistance

Forward resistance is a resistance offered by the p-n junction diode when it is forward biased.

In a forward biased p-n junction diode, two type of resistance takes place based on the voltage applied.

The two types of resistance takes place in forward biased diode are

1. Static resistance or DC resistance
2. Dynamic resistance or AC resistance

Static resistance or DC resistance

When forward biased voltage is applied to a diode that is connected to a DC circuit, a DC or direct current flows through the diode. Direct current or electric current is nothing but the flow of charge carriers (free electrons or holes) through a conductor. In DC circuit, the charge carriers flow steadily in single direction or forward direction.

The resistance offered by a p-n junction diode when it is connected to a DC circuit is called static resistance.

Static resistance is also defined as the ratio of DC voltage applied across diode to the DC current or direct current flowing through the diode.

The resistance offered by the p-n junction diode under forward biased condition is denoted as Rf.

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Dynamic resistance or AC resistance:

The dynamic resistance is the resistance offered by the p-n junction diode when AC voltage is applied.

When forward biased voltage is applied to a diode that is connected to AC circuit, an AC or alternating current flows though the diode.

In AC circuit, charge carriers or electric current does not flow in single direction. It flows in both forward and reverse direction.

Dynamic resistance is also defined as the ratio of change in voltage to the change in current. It is denoted as rf.

Dynamic resistance is also defined as the ratio of change in forward voltage to the change in forward current. It is denoted as rf.

Reverse resistance

Reverse resistance is the resistance offered by the p-n junction diode when it is reverse biased.

When reverse biased voltage is applied to the p-n junction diode, the width of depletion region increases. This depletion region acts as barrier to the electric current. Hence, a large amount of electric current is blocked by the depletion region. Thus, reverse biased diode offer large resistance to the electric current.

The resistance offered by the reverse biased p-n junction diode is very large compared to the forward biased diode. The reverse resistance is in the range of mega ohms (MΩ).

Diode junction capacitance:

Transition and Diffusion capacitance:

Transition capacitances:

1. When P-N junction is reverse biased the depletion region act as an insulator or as a dielectric medium and the p-type an N-type region have low resistance and act as the plates.

2. Thus this P-N junction can be considered as a parallel plate capacitor.

3. This junction capacitance is called as space charge capacitance or transition capacitance and is denoted as CT .

4. Since reverse bias causes the majority charge carriers to move away from the junction , so the thickness of the depletion region denoted as W increases with the increase in reverse bias voltage.

5. This incremental capacitance CT may be defined as

CT = dQ/dV,

Where dQ is the increase in charge and dV is the change or increase in voltage.

6. The depletion region increases with the increase in reverse bias potential the resulting transition capacitance decreases.

7. The formula for transition capacitance is given as CT = Aε/W, where A is the cross sectional area of the region, and W is the width.

Diffusion capacitance:

1. When the junction is forward biased, a capacitance comes into play , that is known as diffusion capacitance denoted as CD. It is much greater than the transition capacitance.

2. During forward biased the potential barrier is reduced. The charge carriers moves away from the junction and recombine.

3. The density of the charge carriers is high near the junction and reduces or decays as the distance increases.

4. Thus in this case charge is stored on both side of the junction and varies with the applied potential. So as per definition change in charge with respect to applied voltage results in capacitance which here is called as diffusion capacitance.

5. The formula for diffusion capacitance is CD = τID / ηVT , where τ is the mean life time of the charge carrier, ID is the diode current and VT is the applied forward voltage, and η is generation recombination factor.

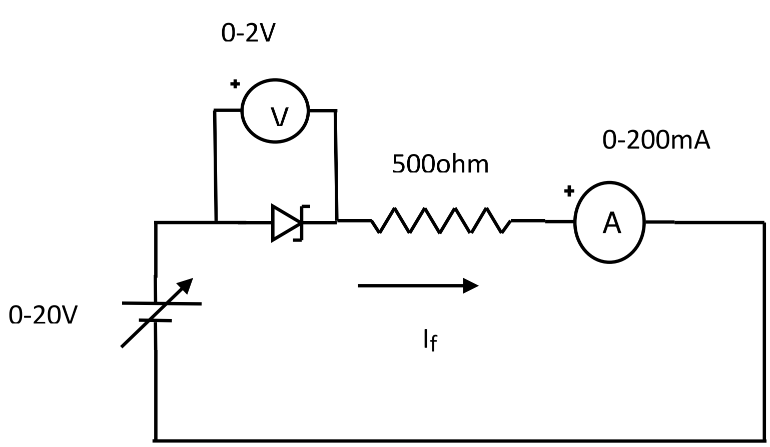
6. The diffusion capacitance is directly proportional to the diode current.7. In forward biased CD >> CT . And thus CT can be neglected.

Zener Diode :

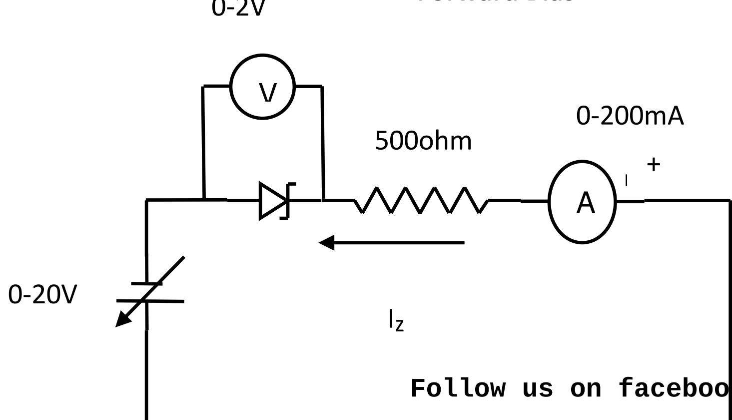
The Zener diode is also a P-N junction diode (silicon), the difference being that it has a sharp and well-defined break down under reverse biased condition. This breakdown voltage Vz is known as the Zener breakdown voltage. The Zener voltage can be precisely set by controlling doping level of P and N materials of the Zener during the manufacturing process.

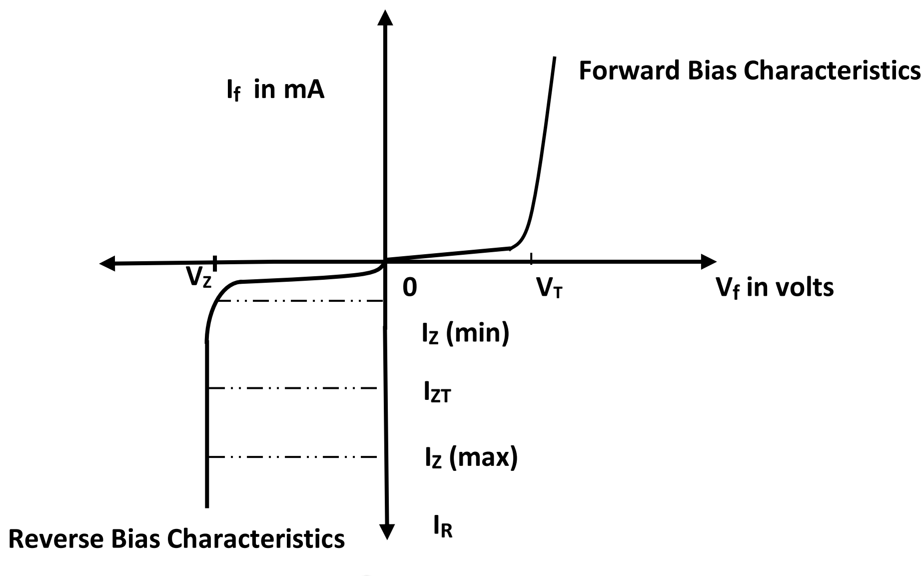
Under forward bias condition, the Zener diode behaves like a normal Silicon rectifier diode. The Zener diode is operated only beyond reverse breakdown region. When the junction breaks down, current flows through it. This heavy current may be due to Zener breakdown or Avalanche break down phenomenon or both.

In the breakdown region, the voltage drop across the Zener diode is constant irrespective of current through it. This property of Zener diode makes it useful as a voltage-regulating device.



Forward Bias





V-I Characteristics of Zener diode

The circuit diagram to plot the VI characteristics of a zener diode is shown. Zener doide is a special diode with increased amounts of doping. This is to compensate for the damage that occurs in the case of a pn junction diode when the reverse bias exceeds the breakdown voltage and thereby current increases at a rapid rate.

Applying a positive potential to the anode and a negative potential to the cathode of the zener diode establishes a forward bias condition. The forward characteristic of the zener diode is same as that of a pn junction diode i.e. as the applied potential increases the current increases exponentially. Applying a negative potential to the anode and positive potential to the cathode reverse biases the zener diode.

As the reverse bias increases the current increases rapidly in a direction opposite to that of the positive voltage region. Thus under reverse bias condition breakdown occurs. It occurs because there is a strong electric filed in the region of the junction that can disrupt the bonding forces within the atom and generate carriers. The breakdown voltage depends upon the amount of doping. For a heavily doped diode depletion layer will be thin and breakdown occurs at low reverse voltage and the breakdown voltage is sharp. Whereas a lightly doped diode has a higher breakdown voltage.

The maximum reverse bias potential that can be applied before entering the zener region is called the Peak Inverse Voltage referred to as PIV rating or the Peak Reverse Voltage Rating (PRV rating).

Varactor Diode:

Varactor or varicap diodes are used mainly in radio frequency (RF) circuits to be able to provide a capacitance that can be varied by changing a voltage in an electronics circuit. This can be used for tuning circuits including radio frequency oscillators and filters.

Although both names: varactor and varicap diode are used, they are both the same form of diode. The name varactor meaning variable reactor, or reactance, and varicap meaning variable capacitance (vari-cap).

Varactor diode applications:

Varactor diodes are widely used within RF circuits. They provide a method of varying the capacitance within a circuit by the application of a control voltage. This gives them an almost unique capability and as a result varactor diodes are widely used within the RF industry.

Although varactor diodes or varicap diodes can be used many different circuits, they find uses in two main areas:

Voltage controlled oscillators, VCOs: Voltage controlled oscillators are used in many different circuits. One major area is for the oscillator within phased locked loops. In turn these can be used as FM demodulators or within frequency synthesizers. The varactor diode is a key component within the voltage controlled oscillator.

RF filters: Using varactor diodes makes it possible to tune filters. Tracking filters may be needed in receiver front end circuits where they enable the filters to track the incoming received signal frequency. Again this can be controlled using a control voltage. Typically this might be provided under microprocessor control via a digital to analogue converter.

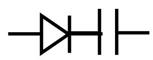
The capacitance of the capacitor is dependent upon the area of the plates - the larger the area the greater the capacitance, and also the distance between them - the greater the distance the smaller the level of capacitance.

A reverse biased diode has no current flowing between the P-type area and the N-type area. The N-type region and the P-type regions can conduct electricity, and can be considered to be the two plates, and the region between them - the depletion region is the insulating dielectric. This is exactly the same as the capacitor above.

As with any diode, if the reverse bias is changed so does the size of the depletion region. If the reverse voltage on the varactor or varicap diode is increased, the depletion region of the diode increases and if the reverse voltage on varactor diode is decreased the depletion region

narrows. Therefore by changing the reverse bias on the diode it is possible to change the capacitance.

Varactor or varicap circuit symbol

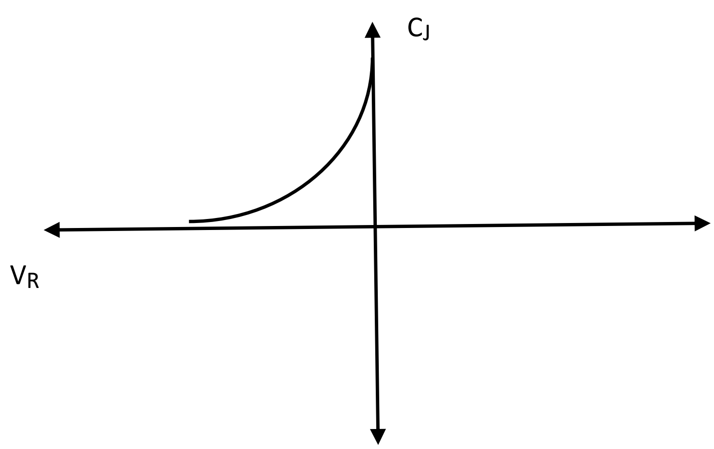


Varactor Diode

The varactor diode or varicap diode is shown in circuit diagrams or schematics using a symbol that combines the diode and capacitor symbols. In this way it is obvious that it is being used as a variable capacitor rather than a rectifier.

When operated in a circuit, it is necessary to ensure the varactor diode remains reverse biased. This means that the cathode will be positive with respect to the anode, i.e. the cathode of the varactor will be more positive than the anode.

As a result, one can conclude that the capacitance of the varactor diode can be varied by varying the magnitude of the reverse bias voltage as it varies the width of the depletion region, d. Also it is evident from the capacitance equation that d is inversely proportional to C. This means that the junction capacitance of the varactor diode decreases with an increase in the depletion region width caused to due to an increase in the reverse bias voltage (VR), as shown by the graph in Figure below. Meanwhile it is important to note that although all the diodes exhibit the similar property, varactor diodes are specially manufactured to achieve the objective. In other words varactor diodes are manufactured with an intention to obtain a definite C-V curve which can be accomplished by controlling the level of doping during the process of manufacture. Depending on this, varactor diodes can be classified into two types viz., abrupt varactor diodes and hyper-abrupt varactor diodes, depending on whether the p-n junction diode is linearly or non-linearly doped (respectively).



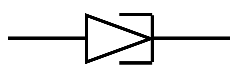
Characteristic curves of varactor

Tunnel Diode:

A tunnel diode or Esaki diode is a type of semiconductor diode that is capable of very fast operation, well into the microwave frequency region, by using the quantum mechanical effect called "Tunneling".

A tunnel diode is a high conductivity two terminal P-N Junction diode doped heavily about 1000 times higher than a conventional junction diode. Tunnel diodes are useful in many circuit applications in microwave amplification, microwave oscillation and binary memory.

The tunnel diode exhibits a special characteristic know as negative resistance. This feature makes it useful in oscillator and microwave amplifier applications. Tunnel diodes are constructed with germanium or gallium arsenide by doping the p and n regions much more heavily than in a conventional rectifier diode.

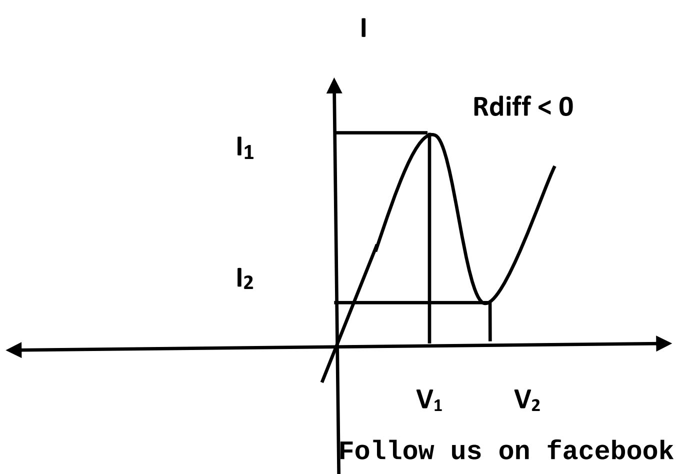


Tunnel Diode

This heavy doping allows conduction for all reverse voltages so that there is no breakdown effect as with the conventional rectifier diode.

Working of Tunnel Diode:

When a small forward bias voltage is applied across a tunnel diode, it begins to conduct current. As the voltage is raised, the current increases and attains a peak value known as peak current. If the current is increased a little more, the current actually begins to decreases until it reaches a low point called the valley current. If the voltage is increased further yet, the current begins to increase again, the time without decreasing into another "valley". The region on the graph where the current is decreasing while applied voltage is increasing is known as the region of the negative resistance.



V

Mechanics behind working:

According to classical mechanics theory, a particle must have an energy at least equal to the the height of a potential-energy barrier if it has to move from one side of the barrier to the other. In other words, energy has to be supplied from some external source so that the electrons on N side of junction climb over the junction barrier to reach the P-side.

However if the barrier is thin such as in tunnel diode ,the Schrodinger equation(Quantum Mechanics) indicates that there is a large probability that an electron will penetrate through the barrier. This will happen without any loss of energy on the part of electron. This quantum mechanical behavior is referred to as tunneling and the high-impurity P-N junction devices are called tunnel-diodes. The tunneling phenomenon is a majority carrier effect.

Why tunneling?

It is that the reduced depletion layer can form result in carriers "punching through" the junction with the velocity of light even when they do not possess enough energy to overcome the potential barrier. The result is that large forward current is produced at relatively low forward voltage (less than 100mv) such a mechanism of conduction in which charge carriers (possessing very little energy) punch through a barrier directly instead of climbing over it is called tunnelling. That's why such diodes are known as tunnel diodes. Because of heavy doping the tunnel diode can conduct in reverse as well as in formed direction but it is usually used in forward biased mode.

Reverse Bias

In the tunnel diode, the dopant concentration in the p and n layers are increased to the point where the reverse breakdown voltage becomes zero and the diode conducts in the reverse direction.

Applications of Tunnel Diode

The tunnel diode showed great promise as an oscillator and high-frequency threshold (trigger) device since it would operate at frequencies far greater than the tetrode would, well into the microwave bands.

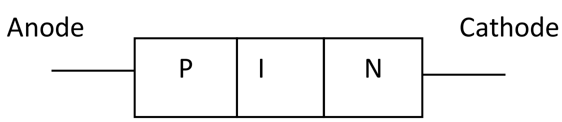
Applications for tunnel diodes included local oscillators for UHF television tuners, trigger circuits in oscilloscopes, high speed counter circuits, and very fast-rise time pulse generator circuits.

The tunnel diode can also be used as low-noise microwave amplifier.

Tunnel diodes are also relatively resistant to nuclear radiation, as compared to other diodes. This makes them well suited to higher radiation environments, such as those found in space applications.

PIN Diode:

The PIN diode can be shown diagrammatically as being a PN junction, but with an intrinsic layer between the PN and layers. The intrinsic layer of the PIN diode is a layer without doping, and as a result this increases the size of the depletion region - the region between the P and N layers where there are no majority carriers. This change in the structure gives the PIN diode its unique properties.

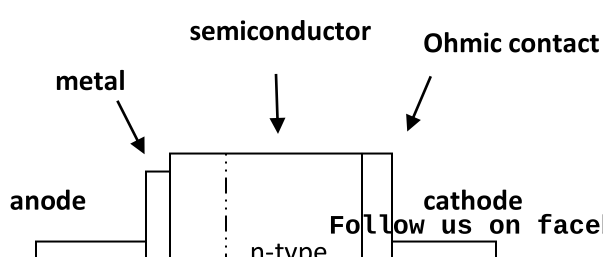


Schottky Diode:

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.

Physical construction:

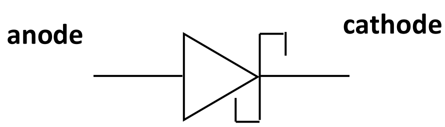
A Schottky barrier diode is shown in the figure below.



A metal semiconductor junction is formed at one end, it is a unilateral junction. Another metal semiconductor contact is formed at the other end. It is an ideal Ohmic bilateral contact with no potential existing between metal and semiconductor and is non rectifying. The built-in potential across the open circuited Schottky barrier diode characterizes the Schottky barrier diode. It is a function of temperature and doping. It decreases with increasing temperature and doping concentration in N type semiconductor. The typical metals used in the manufacture of Schottky barrier diode are platinum, chromium, tungsten Aluminium, gold etc. and the semiconductor used is N type silicon is used.

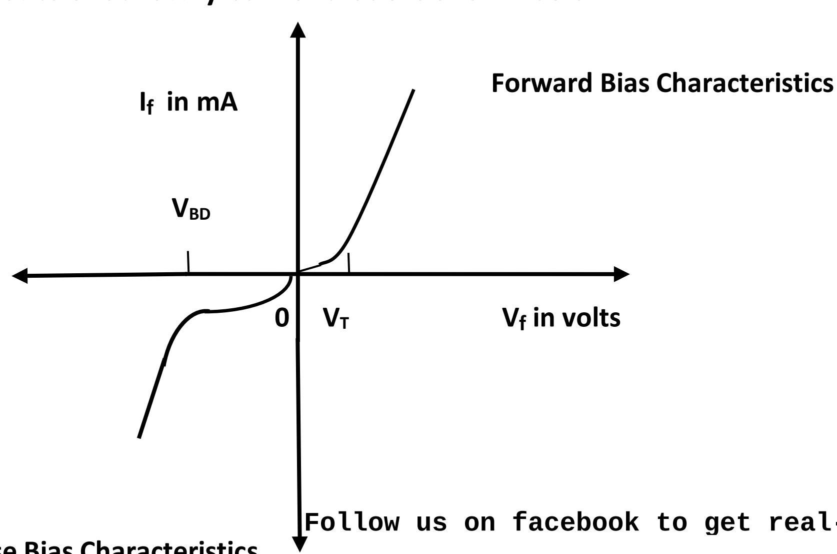
Symbol of Schottky Diode:

A Schottky barrier diode is a two terminal device with metal terminal acting as anode and semiconductor terminal acting as anode. The circuit symbol of Schottky barrier diode is shown in the figure.



VI characteristics of Schottky barrier diode:

The VI characteristics of Schottky barrier diode is shown below



From the VI characteristics it is obvious that the VI characteristics of Schottky barrier diode is similar to normal PN junction diode with the following exceptions

The forward voltage drop of Schottky barrier diode is low compared to normal PN junction diode. The forward voltage drop of Schottky barrier diode made of silicon exhibits a forward voltage drop of 0.3 volts to o.5 volts.

The forward voltage drop increases with the increasing doping concentration of n type semiconductor.

The VI characteristics of Schottky barrier diode is Steeper compared to VI characteristics of normal PN junction diode due to high concentration of current carriers.

LED:

Light Emitting Diodes (LEDs) are the most widely used semiconductor diodes among all the different types of semiconductor diodes available today. Light emitting diodes emit either visible light or invisible infrared light when forward biased. The LEDs which emit invisible infrared light are used for remote controls.

A light Emitting Diode (LED) is an optical semiconductor device that emits light when voltage is applied. In other words, LED is an optical semiconductor device that converts electrical energy into light energy.

When Light Emitting Diode (LED) is forward biased, free electrons in the conduction band recombines with the holes in the valence band and releases energy in the form of light.

The process of emitting light in response to the strong electric field or flow of electric current is called electroluminescence.

A normal p-n junction diode allows electric current only in one direction. It allows electric current when forward biased and does not allow electric current when reverse biased. Thus, normal p-n junction diode operates only in forward bias condition.

Like the normal p-n junction diodes, LEDs also operates only in forward bias condition. To create an LED, the n-type material should be connected to the negative terminal of the battery and p-type material should be connected to the positive terminal of the battery. In other words, the n-type material should be negatively charged and the p-type material should be positively charged.

The construction of LED is similar to the normal p-n junction diode except that gallium, phosphorus and arsenic materials are used for construction instead of silicon or germanium materials.

In normal p-n junction diodes, silicon is most widely used because it is less sensitive to the temperature. Also, it allows electric current efficiently without any damage. In some cases, germanium is used for constructing diodes.

However, silicon or germanium diodes do not emit energy in the form of light. Instead, they emit energy in the form of heat. Thus, silicon or germanium is not used for constructing LEDs.

Layers of LED

Light Emitting Diode (LED) consists of three layers: p-type semiconductor, n-type semiconductor and depletion layer. The p-type semiconductor and the n-type semiconductor are separated by a depletion region or depletion layer.

P-type semiconductor

When trivalent impurities are added to the intrinsic or pure semiconductor, a p-type semiconductor is formed.

In p-type semiconductor, holes are the majority charge carriers and free electrons are the minority charge carriers. Thus, holes carry most of the electric current in p-type semiconductor.

N-type semiconductor

When pentavalent impurities are added to the intrinsic semiconductor, an n-type semiconductor is formed.

In n-type semiconductor, free electrons are the majority charge carriers and holes are the minority charge carriers. Thus, free electrons carry most of the electric current in n-type semiconductor.

Depletion layer or region

Depletion region is a region present between the p-type and n-type semiconductor where no mobile charge carriers (free electrons and holes) are present. This region acts as barrier to the electric current. It opposes flow of electrons from n-type semiconductor and flow of holes from p-type semiconductor.

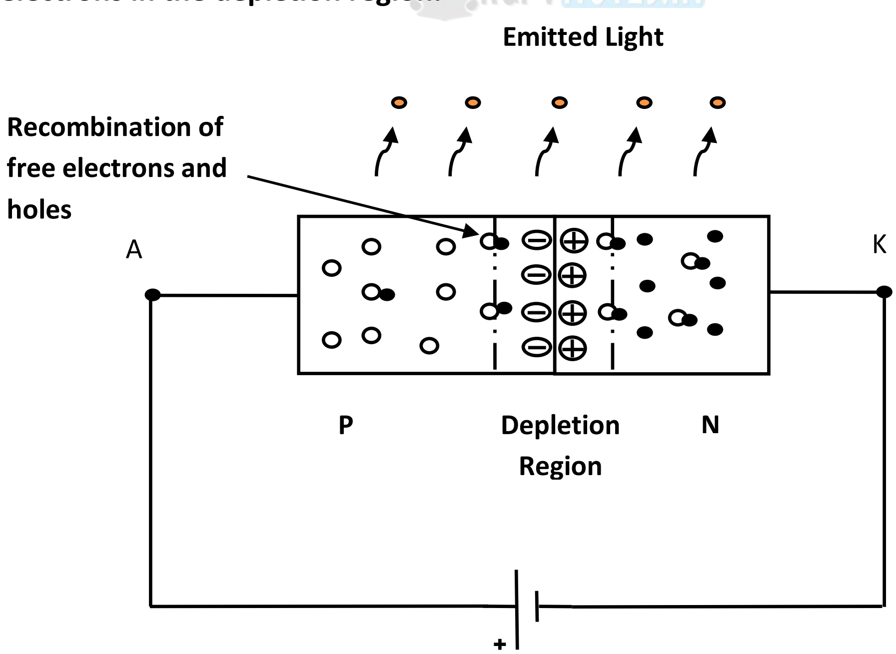
To overcome the barrier of depletion layer, we need to apply voltage which is greater than the barrier potential of depletion layer.

If the applied voltage is greater than the barrier potential of the depletion layer, the electric current starts flowing.

How Light Emitting Diode (LED) works?

Light Emitting Diode (LED) works only in forward bias condition. When Light Emitting Diode (LED) is forward biased, the free electrons from n-side and the holes from p-side are pushed towards the junction.

When free electrons reach the junction or depletion region, some of the free electrons recombine with the holes in the positive ions. We know that positive ions have less number of electrons than protons. Therefore, they are ready to accept electrons. Thus, free electrons recombine with holes in the depletion region. In the similar way, holes from p-side recombine with electrons in the depletion region.



Because of the recombination of free electrons and holes in the depletion region, the width of depletion region decreases. As a result, more charge carriers will cross the p-n junction.

Some of the charge carriers from p-side and n-side will cross the p-n junction before they recombine in the depletion region. For example, some free electrons from n-type semiconductor cross the p-n junction and recombines with holes in p-type semiconductor. In the similar way, holes from p-type semiconductor cross the p-n junction and recombines with free electrons in the n-type semiconductor.

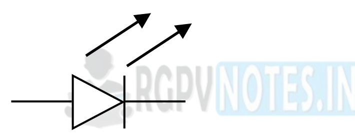
Thus, recombination takes place in depletion region as well as in p-type and n-type semiconductor.

The free electrons in the conduction band releases energy in the form of light before they recombine with holes in the valence band.

In silicon and germanium diodes, most of the energy is released in the form of heat and emitted light is too small.

However, in materials like gallium arsenide and gallium phosphide the emitted photons have sufficient energy to produce intense visible light.

Light emitting diode (LED) symbol:

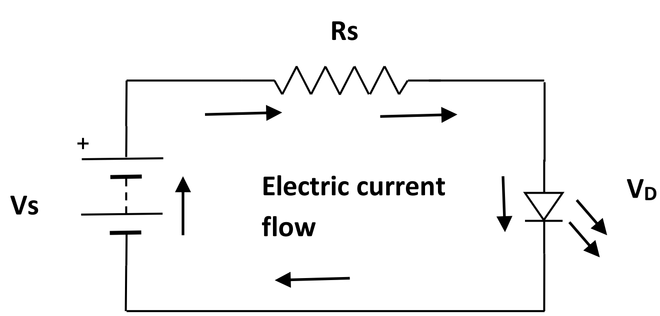


The symbol of LED is similar to the normal p-n junction diode except that it contains arrows pointing away from the diode indicating that light is being emitted by the diode.

LEDs are available in different colors. The most common colors of LEDs are orange, yellow, green and red.

The schematic symbol of LED does not represent the color of light. The schematic symbol is same for all colors of LEDs. Hence, it is not possible to identify the color of LED by seeing its symbol.

Biasing of LED:



The safe forward voltage ratings of most LEDs are from 1V to 3 V and forward current ratings is from 200 mA to 100 mA.

If the voltage applied to LED is in between 1V to 3V, LED works perfectly because the current flow for the applied voltage is in the operating range. However, if the voltage applied to LED is increased to a value greater than 3 volts. The depletion region in the LED breaks down and the electric current suddenly rises. This sudden rise in current may destroy the device.

To avoid this we need to place a resistor (Rs) in series with the LED. The resistor (Rs) must be placed in between voltage source (Vs) and LED.

The resistor placed between LED and voltage source is called current limiting resistor. This resistor restricts extra current which may destroy the LED. Thus, current limiting resistor protects LED from damage.

The current flowing through the LED is mathematically written as

Forward current in LED formula

Where, $$\mathrm{If} = (\mathrm{Vs} - \mathrm{Vd})/\mathrm{Rs}$$

If = Forward current

Vs = Source voltage or supply voltage

Vd = Voltage drop across LED

Rs = Resistor or current limiting resistor

Voltage drop is the amount of voltage wasted to overcome the depletion region barrier (which leads to electric current flow).

The voltage drop of LED is 2 to 3V whereas silicon or germanium diode is 0.3 or 0.7 V.

Therefore, to operate LED we need to apply greater voltage than silicon or germanium diodes.

Light emitting diodes consume more energy than silicon or germanium diodes to operate.

Output characteristics of LED:

The amount of output light emitted by the LED is directly proportional to the amount of forward current flowing through the LED. More the forward current, the greater is the emitted output light. The graph of forward current vs output light is shown in the figure.

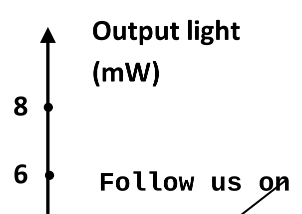


Photo Diode:

Photo means light and diode means a device consisting of two electrodes. A photo diode is a light sensitive electronic device capable of converting light into a voltage or current signal. It works on the principle of photo generation.

Symbol of Photo diode

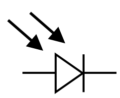


Photo diode has two terminals anode and cathode with the arrows indicating that the light rays falling on photo diode reflecting its significance as a photo detector.

Types of photo diodes

There are mainly three types of photo diodes

PN junction photo diode

Avalanche photo diode

PIN photo diode

Normal PN junction photo diode is used in low frequency and low sensitive applications. When high frequency of operation and high sensitivity is needed avalanche photo diode or PIN photo diodes are used.

Physical Structure of photo diode

A normal PN junction photo diode is made by sandwiching a P type semiconductor into N type semiconductor. All the sides of PN junction diode is enclosed in metallic case or painted black except for one side on which radiation is allowed to fall.

Modes of operation of Photo diode

A photo sensitive diode can be operated mainly in two modes

Photo conductive mode

Photo voltaic mode

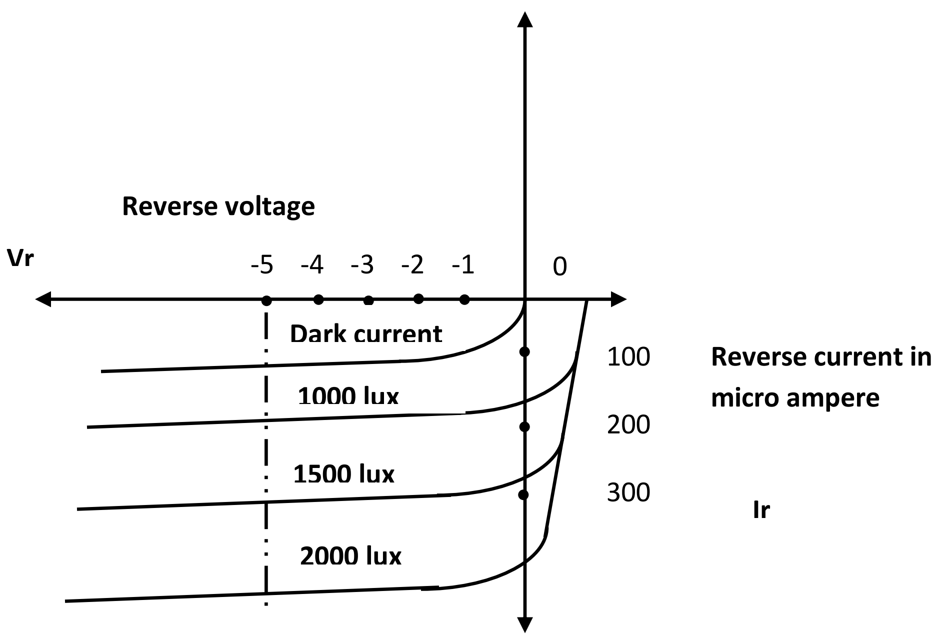
The photo diodes used as photo detectors are optimized (in the physical construction of the device itself) to have fast response times whereas the photo diodes used in electrical energy generation are optimized to have high efficiency of energy conversion. The photo detectors are operated in photo conductive mode. Solar cells are operated in Photo voltaic mode.

Principle of operation

When a PN junction is illuminated with light, it ionizes covalent bonds and new hole, electron pairs are generated in excess of thermally generated pairs. If the photo generation occurs at a distance of the diffusion length order or less depletion layer the photo generated electron hole pairs are swept across by the applied reverse bias field. This mode of operation of photo diode is called photo conductive mode. The photo current varies almost linearly with incident light flux or optical power. The mode of operation of photo diode is called photo conductive diode.

V-I characteristics of photo diode

The V-I characteristics of a photo diode is shown in the figure



A photo diode is always operated in reverse bias mode. From the photo diode characteristics it is seen clearly that the photo current is almost independent of applied reverse bias voltage. For zero luminance the photo current is almost zero except for small dark current. It is of the order of nano amperes. As optical power increases the photo current also increases linearly. The maximum photo current is limited by the power dissipation of the photo diode.

Disadvantages of normal PN junction photo diodes:

Normal PN junction photo diodes have very high response times.

It has very low sensitivity

Applications of photo diodes:

Photo diodes are used as photo detectors

Photo diodes are used in providing electric isolation using a special circuitry called as Opto-couplers. Opto-coupler is an electronic component which is used in coupling optically the two isolated circuits by using light. The two circuits are optically coupled but electrically isolated. It is a combination of light emitting diode and photo diode (or) avalanche diode (or) photo transistor. Opto-couplers are faster than the conventional devices.

Switching characteristics of diode:

When diode is switched from forward biased to the reverse biased state or viceversa, it takes finite time to attain a steady state.

This time consists of a transient and an interval of time before the diode attains a steady state. The behavior of the diode during this time is called switching characteristics of the diode.

In the forward-bias state, there are a large number of electrons from the n

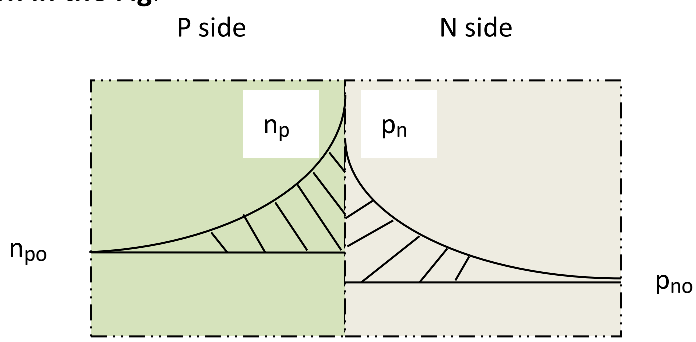
side diffusing into p side and a large number of holes diffusing into n side from p side. This diffusion process establishes a large number of minority carriers in each material.

When forward biased, let n is concentration of electrons on p side at thermal equilibrium and p is concentration of holes on n side thermal equilibrium. This is concentration level far away from the junction.

It increases towards the junction and becomes n and Pn on p and n side respectively in steady state. These minority charge carriers are supplied from other side of the junction, where those carriers are majority in number.

When the diode is reverse biased, again far from the junction the minority charge concentration is n on p side and Pno on n side.

In reverse biased condition, as they approach the junction, they quickly cross the junction. Hence minority carrier concentration decreases to zero at the junction in steady state. This is shown in the Fig.



Now when a forward biased diode is suddenly reverse biased, it takes finite time to change the minority charge carrier concentration and to attain new steady state value.

The diode cannot attain steady state till the minority charge carrier concentration changes from that corresponding to the forward biased to that corresponding to the reverse biased.

Till the excess charge carrier concentration pn-pno and np-npo reduces to zero, the diode continues to conduct. This current is decided by the current limiting external resistance connected in the circuit.

Hence in switching applications, the time required by the diode to attain new steady state, plays an important role.

