Content:

Diodes: *Direct and indirect band gap, Band gap engineering, P-N junction diode-forward and reverse bias, diode equation, V-I characteristic, Application: bridge rectifier, breakdown mechanism in diodes: Avalanche & Zener breakdown, Zener diode as voltage regulator.*
Transistors: *Bi-junction polar transistor, V-I characteristics in Common Emitter, Common Base and Common Collector configuration, CE configuration as an amplifier. Numerical problems.*

Introduction

A semiconductor device is a electronic equipment that is made from a material that is a semiconductor, such as silicon or germanium. These materials are used to create devices such as transistors, diodes, and solar cells, which are used in a wide range of electronic devices, including computers, smartphones, and televisions. Semiconductor devices are important because they are smaller, faster, and more energy-efficient than traditional electronic devices, and they are also more reliable. They are used in many different fields such as microprocessors, memory devices and power electronic devices among many others.

Band theory of solids

The band theory of solids is a model that describes the electronic structure of solid materials, such as metals, semiconductors, and insulators. The theory explains how the electrons in a solid interact with each other and with the atoms that make up the solid, giving rise to unique electronic properties.

In a solid, the electrons are not bound to individual atoms, but are free to move throughout the material. According to the band theory, the electrons in a solid occupy energy levels that are grouped together in bands. The lowest energy band, called the valence band, is fully occupied by electrons that are tightly bound to the atoms. The next energy band, called the conduction band, is partially or completely empty and is separated from the valence band by an energy gap known as the band gap.

The energy gap between the valence and conduction bands determines whether a material is a conductor, semiconductor, or insulator is as shown in figure 1. The band theory predicts that metals have a partially filled conduction band, which allows the electrons to move freely through the material, resulting in high electrical conductivity. In contrast, insulators have a large band gap between the valence and conduction bands, which means that electrons cannot easily move through the material, resulting in low conductivity. Semiconductors have a small band gap, which allows electrons to move through the material under certain conditions, making them useful for electronic devices.

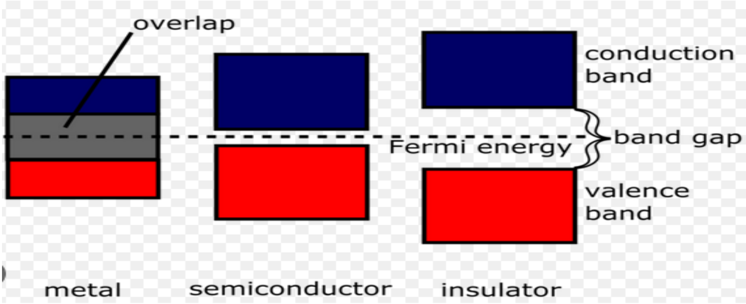


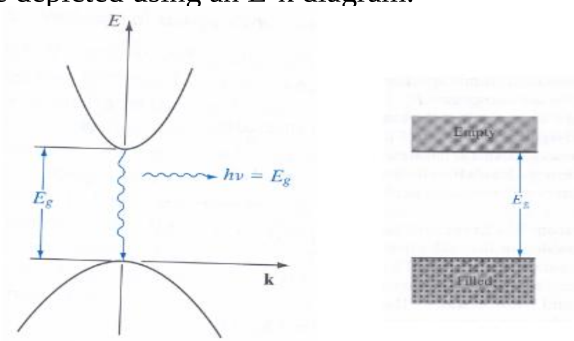
Figure 1: Band diagram for conductor, semiconductor and insulator

In summary, the band theory of solids provides a fundamental understanding of the electronic structure of solids and has important implications for the design and development of electronic devices and materials.

E-k diagram and effective mass:

The E-k diagram is a useful tool for understanding the relationship between energy and momentum in quantum mechanics, and can be applied in a variety of fields including materials science, solid-state physics, and particle physics.

In condensed matter physics, an E-k diagram as shown in figure 2 represents the energy of electrons (E) as a function of their momentum (k) in a crystalline material. The band structure of a material, which describes the allowed energy levels for electrons in the material, can be depicted using an E-k diagram.



The top of the valence band and the bottom of the conduction band are similar parabolic functions.

Figure 2: E-k diagram

In the E-k diagram, the energy of a particle is determined by its momentum, as well as other physical properties such as mass and potential energy. The electrons in a crystal are not completely free, but instead interact with the periodic potential of the crystal lattice. The slope of the energy curve on the diagram represents the particle's velocity, with steeper slopes indicating higher velocities.

The effective mass can be calculated from the curvature of the E-k diagram near the band edges using the following expression:

$$m* = \frac{\hbar^2}{\frac{d^2E}{dk^2}}$$

Where m* is the effective mass, h is Planck's constant, E is the energy, and k is the momentum. The effective mass is usually expressed in terms of the free electron mass (m_e), which is the mass of an electron in vacuum. For example, if the effective mass of an electron is $0.5m_e$, it means that the electron behaves as if it has half the mass of a free electron.

In summary, the E-k diagram and effective mass expression are important tools for understanding the electronic properties of semiconductors. The E-k diagram provides a graphical representation of the electronic band structure, while the effective mass expression relates the momentum and velocity of the charge carriers.

Direct and Indirect band gap semiconductors

Semiconductors are materials that have an energy gap between their valence band and conduction band, which can be manipulated by introducing impurities or changing the material's composition. These energy gaps are responsible for the unique electrical and optical properties of semiconductors, making them essential for modern electronics and optoelectronics.

There are two types of band gaps in semiconductors: direct and indirect. The energy-momentum relationship for electrons in the valence band and conduction band is given by the energy-momentum dispersion relation or the E-k diagram. In this diagram, the horizontal axis represents the momentum (k), while the vertical axis represents the energy (E).

Direct band gap semiconductor:

A direct bandgap semiconductor is a material where the transition of electrons from the valence band to the conduction band can take place without any change in momentum as shown in figure 3. This results in a high probability for direct transitions between the two bands, leading to efficient light emission and absorption. These properties make direct bandgap materials ideal for various optoelectronic applications such as LED lights and solar cells. Examples of direct bandgap semiconductors include GaAs, InP, ZnS, CdSe, CdTe and SiC.

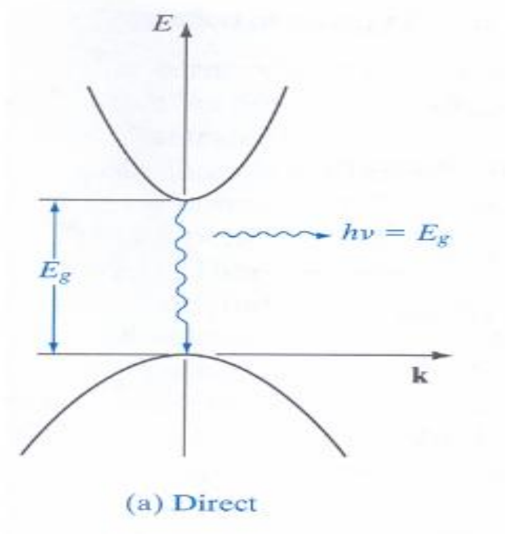


Figure 3: E-k diagram for Direct band gap semiconductor

Indirect band gap semiconductor:

An indirect bandgap semiconductor is a material where the transition of electrons from the valence band to the conduction band requires a change in momentum as shown in figure 4. This means that an electron in the conduction band minimum cannot fall directly to the valence band maximum. It must undergo a momentum as well as energy change as the transition is not occurring at the same value of k.

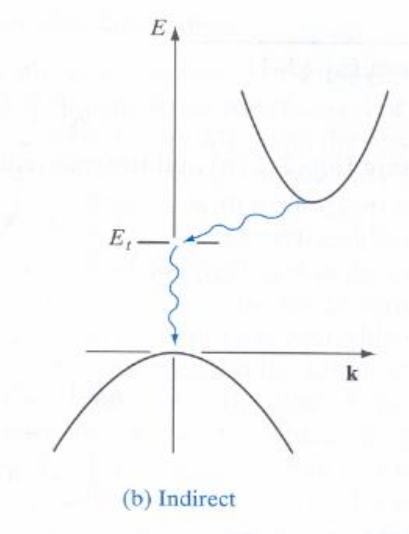


Figure 4: E-k diagram for Indirect band gap semiconductor

A photon by itself cannot excite an electron from the top of valence band to the bottom of conduction band. This is because the photons has sufficient energy to cause the transition but does not possess the necessary momentum. As the photons have zero momentum, the difference in momentum appears in the form of **phonons** (quantum of crystal lattice vibration). Indirect bandgap semiconductors include Si and Ge, and due to the lower probability of light emission, they are less suitable for optoelectronic applications.

Difference between direct and indirect band gap semiconductors

Direct band-gap (DBG) semiconductor	Indirect band-gap (IBG) semiconductor
• A direct bandgap semiconductor is a material where the transition of electrons from the valence band to the conduction band can take place without any change in momentum. • A direct recombination takes place with the release of the energy equal	• An indirect bandgap semiconductor is a material where the transition of electrons from the valence band to the conduction band requires a change in momentum. • Due to a relative difference in the momentum, first, the momentum is

to the energy difference between the recombining particles. • The probability of a radiative recombination is high. • The efficiency factor of a DBG semiconductor is higher. Example: Gallium Arsenide	conserved by release of energy and only after the both the momenta align themselves, a recombination occurs accompanied with the release of energy. • The probability of a radiative recombination is comparatively low. • The efficiency factor of an IBG semiconductor is lower. Example: Silicon and Germanium

Band gap engineering:

Band gap engineering refers to the intentional modification of the electronic band structure of materials, particularly semiconductors, in order to control their electronic and optical properties.

The band gap is the energy difference between the highest energy level of the valence band and the lowest energy level of the conduction band in a material. Semiconductors have a relatively small band gap, which allows them to absorb and emit light at specific wavelengths. By engineering the band gap of a material, researchers can tune its optical and electronic properties to create new applications.

There are several techniques for band gap engineering, including alloying, doping, and quantum confinement. Alloying involves mixing different elements to create a new material with a modified band gap. Doping involves adding impurities to a semiconductor to change its electronic properties. Quantum confinement refers to the confinement of electrons and holes in a small space, such as a quantum dot, which can modify the band gap.

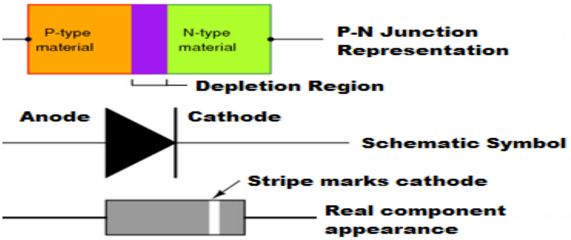
P-N junction: Background information

The construction of solid state electronic device begins with a semiconductor material of highest quality. The three semiconductors are most frequently used in the construction of electronic devices are Ge, Si and GaAs.

A semiconductor material that has been subjected to the doping process is called an extrinsic material. There are two extrinsic materials of immeasurable importance to semiconductor device fabrication are n-type and p-type materials. When a p-type semiconductor and n-type semiconductor are joined metallurgically, a p-n junction is formed. A p-n junction cannot be produced simply by joining two semiconductors. Actual process is a complex one. In practice, such a p-n junction may be prepared by employing two methods 1) Grown junction and 2) Fused junction.

P-N junction:

A diode is a semiconductor device that allows current to flow in only one direction. It consists of a p-n junction, which acts as a barrier that allows current to flow in one direction but not the other. Diodes are used in a variety of electronic circuits, such as rectifiers, voltage regulators, and signal processing circuits. They are also commonly used in power supplies and electronic devices such as televisions and radios.



A simple representation of a p-n junction is shown in the figure.

Diffusion of majority carriers and formation of depletion region:

When a p-type semiconductor and an n-type semiconductor are brought into contact with each other, a diffusion of electrons and holes occurs at the interface due to the concentration gradient of charge carriers. Electrons from the n-type region diffuse across the interface into the p-type region, and combine with holes to form neutral atoms. Similarly, holes from the p-type region diffuse across the interface into the n-type region and combine with electrons to form neutral atoms. This diffusion of charge carriers continues until a depletion region is formed at the interface where there are no free charge carriers.

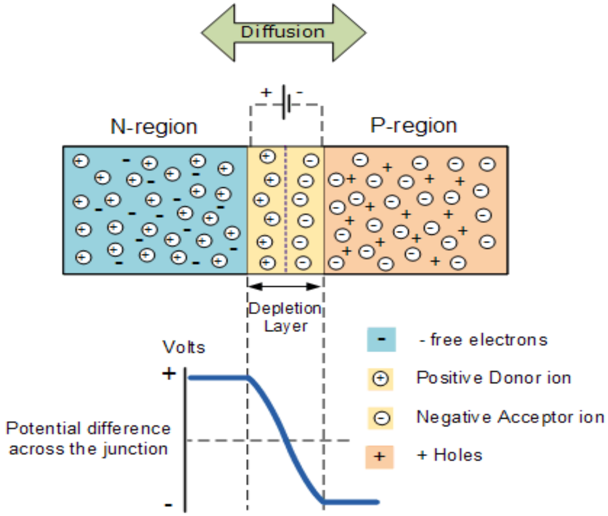


Figure 5: **Depletion region**

The depletion region is shown in figure 5 has a fixed electric field that prevents any further diffusion of charge carriers, and this creates a potential difference across the p-n junction. This potential difference is known as the built-in potential and it acts as a barrier for the flow of electric current in the reverse biased direction.

When a voltage is applied in the forward biased direction, the potential barrier is reduced, allowing electric current to flow through the p-n junction. This forms the basis of many electronic devices such as diodes, transistors, and solar cells.

The diffusion of majority carriers causes diffusion current to flow across the junction. It is easy to see that the current components due to holes and electrons add up although carriers are moving in opposite directions as shown in figure 6. The net diffusion current density flowing across the junction is given by J (diff) = J_{hp}+ J_{en}

Where J_{hp}: hole diffusion current
J_{en}: electron diffusion current

Drift current due to minority carriers:
The field due to space charge causes the flow of minority carriers across the junction. Electrons reaching the edge of the junction on p-region are accelerated by the electric field in to n-region and similarly, the holes reaching the edge of the junction on n-region are accelerated into p-region. As a consequence, an electric current flows across the junction. This current which is caused by electric field is called drift current. The current components due to drift motion of holes and electrons are in same direction and add up to each other as shown in figure 6. The net drift current through the junction is J (drift) = J_{hn} + J_{ep}

Where J_{hn}: hole drift current density
J_{ep} : electron drift current density

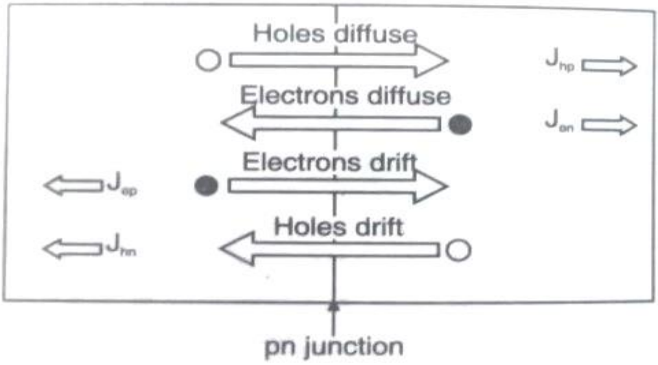
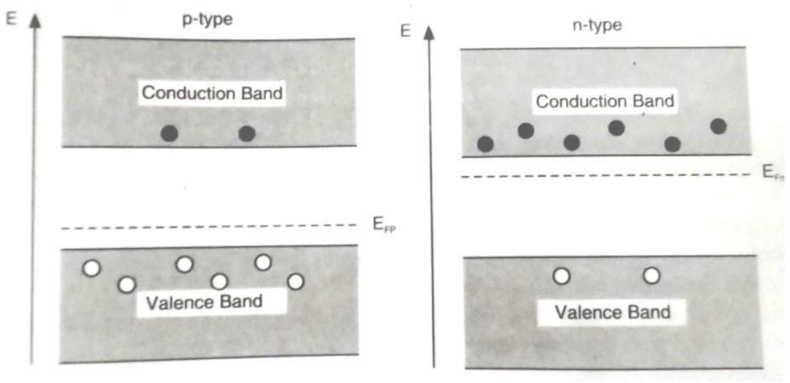


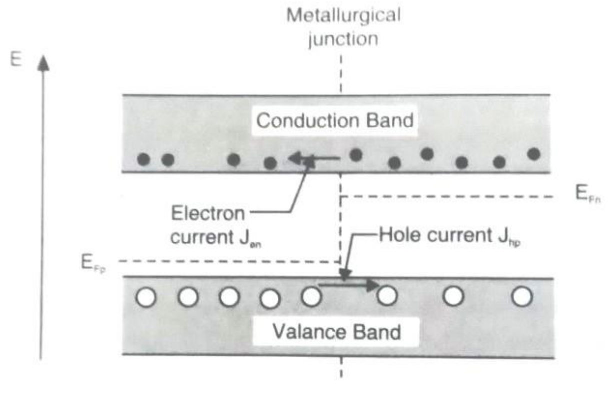
Figure 6: Diffusion and drift current across p-n junction

Energy band diagram of p-n junction at equilibrium:

Let us understand the formation of p-n junction from the point of view of energy band structure. When the two semiconductors are in contact, equilibrium is attained only when there is no net current flow across the junction region. The energy band diagrams of the p and n semiconductors are shown in the figure given below. Note that the Fermi levels E_{Fp} and E_{Fn} are at different levels.



At the instant of joining the levels in the two semiconductors are not aligned is shown in the figure given below.



The occupancy of energy levels by electrons in the conduction band on n-side is high while it is low on p-side. Therefore, the electrons occupying the energy levels in the conduction band on n-side move into the conduction band levels on p-side.

Similarly, the occupancy of energy levels by holes in the valence band on p-side is high while it is low on n-side. Hence, the holes occupying the energy levels in the valence band on p-side move into the valence band levels in n-side.

As high energy electrons leave n-region, the Fermi level E_{Fn} which represents the average energy of electrons move downwards. Since the Fermi level is fixed relative to the band structure of the region, its movement causes downward shift of the entire band structure in the n-region.

On the p-side, holes having higher energy leave the valence band in that region. The direction of decrease in hole energy in upward and hence Fermi level moves E_{Fp} moves upward. Along with E_{Fp}, the entire band structure in the p-region shifts upward. The shifting of energy bands continues till the energy levels E_{Fp} and E_{Fn} attains the same level in both the regions as shown in the figure 7 given below.

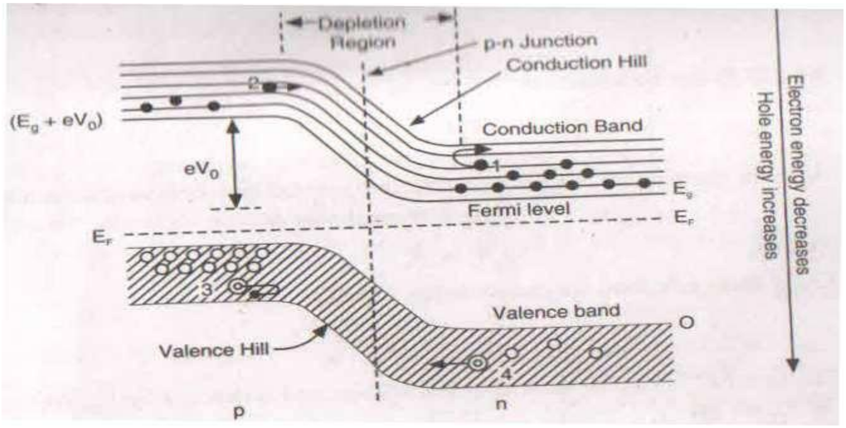


Figure 7: Energy band diagram of p-n junction at equilibrium

When the two levels are equalised, the carrier migration comes to a halt and equilibrium is established. The displacement of the energy bands in opposite directions on both the sides causes a bending of the energy bands in the junction region. Each side takes up a different electrostatic potential. It results in a potential barrier V_o or an energy hill of height eV_o. Electrons in the conduction band of n-region face an energy hill, namely conduction hill. Electrons approaching the junction cannot surmount the conduction hill unless they have minimum energy of eV_o. On the other hand, holes near the junction on the n-side can readily float up the hill irrespective of their energy. Thus the current due to diffusion of majority carriers is balanced by the drift of minority carriers and net current across the p-n junction is zero.

Internal Potential barrier (V_o):

The magnitude of the potential barrier V_o can be estimated from the knowledge of the electron concentrations in the p and n region of the diode. E_g is the edge of the conduction band on the n-side as shown in figure 7. The electron concentration in the conduction band on the n-side can be written as

$$n_n = N_C\ e^{\left[-\left(E_g - E_F\right)/KT\right]} \text{--------}(1)$$

The edge of the conduction band on the p-side is given by (E_g+eV_0). The electron concentration on p-side can be expressed as

$$n_p = N_C\ e^{\left[-\left\{(E_g + eV_o) - E_F/kT\right\}\right]} \text{--------}(2)$$

Dividing equation (1) by (2),we get

$$\frac{n_n}{n_p} = \exp\left[\frac{eV_o}{kT}\right] \text{---------}(3)$$

Equation (3) shows that at thermal equilibrium the concentrations of electrons on both sides of the junction are related through the Boltzmann factor $e^{eVo\ /\ kT}$. The concentrations of holes on both the sides are related by an equation similar to equation (3).

Taking logarithm on both sides of equation (3), we obtain

$$V_o = \frac{kT}{e} \ln \frac{n_n}{n_p} ---------(4)$$

Equation (4) can be written as

$$V_o = \frac{kT}{e} \ln \frac{n_n p_p}{n_p p_p}$$

At room temperature ,all the impurities are ionised and therefore,

we can write $n_n = N_D$ and $p_p = N_A$ Further $n_n p_p = n_i^2$

Using these relations we can write equation (4)as

$$V_o = \frac{kT}{e} \ln \frac{N_D N_A}{n_i^2} --------------(5)$$

The factor $\frac{kT}{e}$ has the dimensions of voltage and isdenoted by V_T,

we get $V_o = V_T \ln \frac{N_D N_A}{n_i^2} --------------(6)$

Equation (6) indicates that the barrier potentia in a junction diode depends on the equilibrium concentrations of the impurities in p and n regions and does not depend on the charge density in the depletion region.

Effect of biasing on the band structure of the p-n junction:

A device is said to be biased when a dc voltage is applied to it. A p-n junction can be biased in two ways.

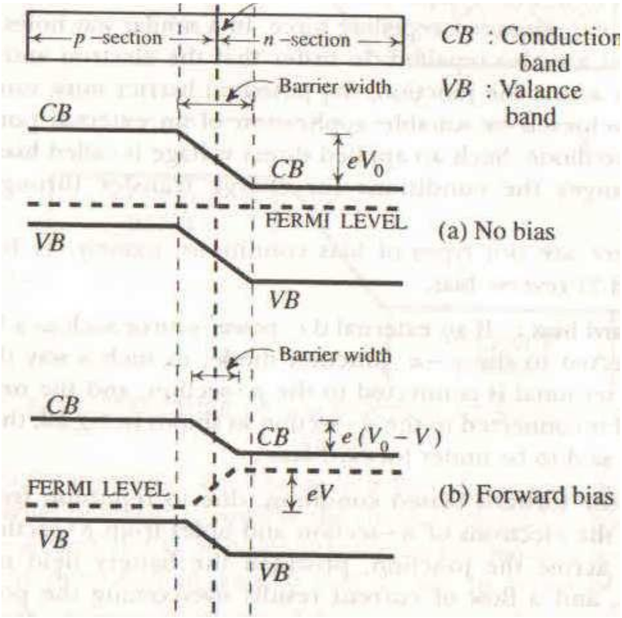
I. **Forward bias:** The positive terminal of the dc voltage source is connected to the p-region and the negative terminal to the n-region.

II. **Reverse bias:** The negative terminal of the dc voltage source is connected to the n-region and the negative terminal to the p-region.

When the diode is subjected to biasing, the equilibrium conditions that were established prior to the application to the application of bias get disturbed, and the relative positions of the energy bands and the Fermi level get displaced in the following manner.

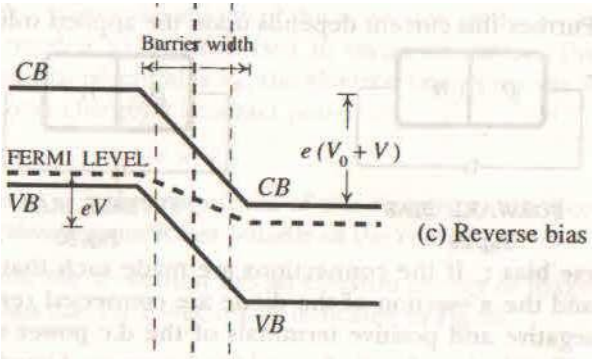
In case of forward bias, since the n-section is connected to the negative terminal of the dc source, the energy of the electron in the n-section increases by an amount of eV, where e is the charge on the electron and V is the applied voltage.

Consequently, the Fermi level rises by a value eV in the n-side with respect to that in p-side. Along with the Fermi level, the companion energy bands on the respective sides also get displaced by the same amount as shown in Figure.



As a result the energy associated with the potential barrier is reduced to $e(V_o\text{-}V)$, Where V_o is the contact potential. Thus for forward biasing the resultant potential across the junction will be the difference of the applied and contact potential. Thus the resultant field across the junction becomes weaker, which in turn renders the depletion region narrower.

In contrast to the above, changes occur in just the opposite way of reverse biasing the diode. In the reverse bias condition, since n-section is connected to the positive terminal of the battery, the electrons in the n-section need more energy to overcome the contact potential. This is equivalent to a reduction in its energy as compared to that in the unbiased state by an equal amount to eV, where V is the applied potential. As a result, the Fermi level on the n-section side gets lowered by eV. The energy bands of both n-section and p-sections also get displaced, in the same direction and by the same amount as that of Fermi level in order to suit the depression caused in the Fermi level position as shown in the figure given below.



Due to the shift in Fermi level, the potential barrier energy increases to $e(V_o+V)$. The higher potential across the junction creates a stronger field in the vicinity of the junction which pushes electrons and holes away. This effect causes the depletion region to become wider.

Ideal diode characteristics:

1. It conducts current in one direction only, and it has zero resistance when forward biased.
2. It blocks current flow in the reverse direction, and it has infinite resistance when reverse biased. The reverse saturation current is zero.

Diode parameters:

1. *Static forward voltage drop (V_F)*: This is a maximum forward voltage for a given forward current, at a given device temperature.

2. *Forward Resistance (R_F)*: This is a static quantity, i.e., it is constant for specific current.

3. *Dynamic or a. c resistance (r_d)*: Suppose, in addition to a d.c current, a small a.c current is superimposed on it in a diode circuit. The resistance that the diode offers to this signal is called dynamic or a.c resistance. At any particular d.c voltage, the a.c resistance of a diode is the reciprocal of the slope of the characteristic at that point.

4. *Reverse Breakdown Voltage (V_{BR}):* If the reverse bias applied to a p-n junction is increased, a point is reached when the junction breaks down and reverse current shoots up to a value limited only by the external resistance connected in series with the junction. This critical value of the voltage is known as the reverse breakdown voltage.

5. *Reverse Saturation Current (I_S)*: The voltage at which the electric current reaches its maximum level and further increase in voltage does not increase the electric current is called **reverse saturation current**.

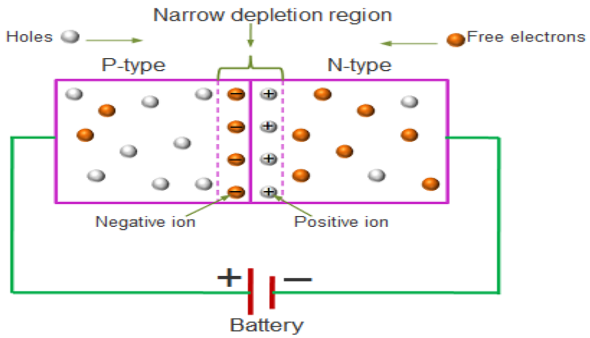
Forward bias I-V characteristics:

A P-N junction is said to be forward-biased, when the p-type is connected to the positive terminal and the n-type region is connected to the negative terminal of a voltage source resulting in a flow of current in the forward direction.This results in the following characteristics:

1. Low resistance: The forward-biased diode offers a low resistance to the flow of current, allowing current to flow easily.

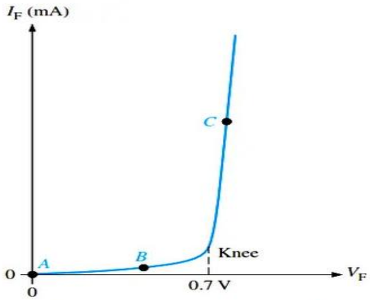
2. Voltage drop: A small voltage drop occurs across a forward-biased diode, which is due to the energy required to move electrons from the n-type material to the p-type material.
3. Increased current: As the voltage across the diode increases, the current through the diode also increases.
4. Continuous conduction: The forward-biased diode allows current to flow continuously as long as the forward voltage is maintained.

These characteristics make the forward-biased diode useful in various applications such as rectifiers, voltage regulators, and power supplies.

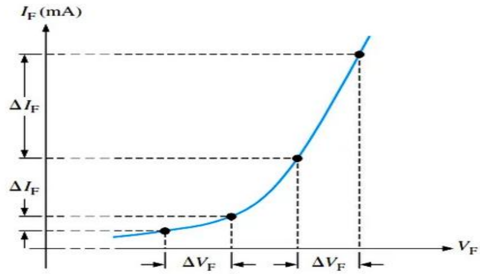


Forward bias

A positive bias voltage is applied to p-type and a negative voltage to the n-type as shown in the figure. As the holes on the p-type are positively charged particles they are repelled from the positive bias terminal and are forced to move towards the junction. Similarly, the electrons on the n-type are repelled by the negative bias terminal are driven towards the junction. Consequently the depletion region is narrowed down and along with it the barrier potential is also reduced. If the applied voltage is gradually increased from zero, the barrier potential too gets gradually smaller and charge carriers readily flow across the junction. Electrons from n-type are attracted across to the positive bias terminal and the holes from the p-type to the negative terminal. Thus, a majority carrier current flows and the junction is forward biased.



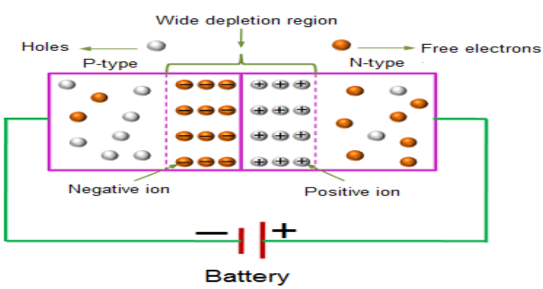
(a) *V-I* characteristic curve for forward bias.



(b) Expanded view of a portion of the curve in part (a). The dynamic resistance r'_d decreases as you move up the curve, as indicated by the decrease in the value of $\Delta V_F / \Delta I_F$.

The graph shows the forward characteristics, i.e., the forward current I_F is plotted against the forward voltage V_F

Reverse bias characteristics:

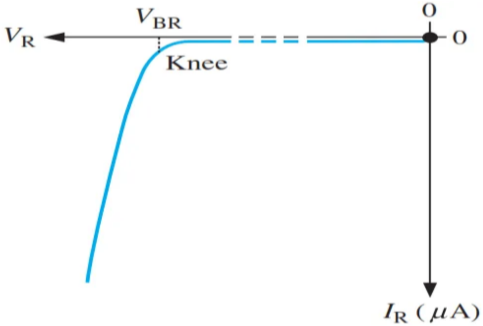


Reverse bias

The process by which, a p-n junction diode blocks the electric current in the presence of applied voltage is called reverse biased p-n junction diode. In reverse biased p-n junction diode, the positive terminal of the battery is connected to the n-type semiconductor material and the negative terminal of the battery is connected to the p-type semiconductor material.

On application of an external bias - positive to n-type and negative to p-type, electrons from the n-type are attracted to the positive bias terminal and holes from the p-type are attracted to the negative terminal. As a result, the depletion region is widened and the barrier potential is increased by the magnitude of the applied voltage. Due to the increase in barrier potential and the resultant electric field, it is not possible for the majority carrier current to flow across the junction and the junction is reverse biased. However, minority carriers generated on either side can still cross the junction.

The phenomenon is shown by the junction reverse characteristics.



A small reverse bias voltage is enough to pull across all available minority carriers across the junction. When all the minority carriers have crossed over, any further increase in bias voltage will not increase in current. This is called reverse saturation current.

For a diode, the reverse saturation current is very much smaller than the forward current (I_F). Hence a reverse biased diode considered to be an open switch. At a particular value of high reverse voltage, the reverse current suddenly shoots up, resulting in overheating and diode is said to be in the breakdown region.

Diode equation:

The diode equation relates the current flowing through a diode to the voltage across it. It is given by:

$$I = I_s\left(e^{\left(\frac{V_D}{\eta^* V_T}\right)} - 1\right) ---------- (1)$$

Where I is the diode current, I_s is the reverse saturation current (a small current that flows when the diode is reverse biased), V_D is the voltage across the diode, η is the ideality factor (a dimensionless parameter that accounts for non-ideal behavior), and V_T is the thermal voltage (kT/e, where k is Boltzmann's constant, T is the temperature in Kelvin, and e is the charge of an electron).

The diode equation can be used to describe the forward and reverse characteristics of a diode.

For the **forward characteristics**, when the diode is forward-biased, its voltage is positive and the current flowing (I_F) through the diode is given by:

$$I_F = I_s\left(e^{\left(\frac{V_D}{\eta^* V_T}\right)} - 1\right) ----------(2)$$

$$When\ V_D >>> V_T,\ e^{\left(\frac{V_D}{\eta^* V_T}\right)} >>>> 1$$

Equation (2) reduces to $I_F = I_s e^{\left(\frac{V_D}{\eta^* V_T}\right)}$

Which shows that that the diode current increases exponentially as the forward voltage increases, and the diode is said to be in the forward-active region.

The forward-bias diode equation is useful for analyzing and designing circuits that use diodes, as it allows us to calculate the expected current flowing through the diode as a function of the applied forward voltage

The diode equation for **reverse bias characteristics** describes the reverse leakage current (I_R) that flows through a diode when it is reverse biased. It is given by:

$$I_R = I_s\left(e^{\left(\frac{V_D}{\eta^* V_T}\right)} - 1\right) ----------(3)$$

When reverse or negative voltage is applied across the diode, V_D is negative.

$$When\ V_D >>> V_T,\ \ e^{\left(\frac{-V_D}{\eta^* V_T}\right)} = \frac{1}{e^{\left(\frac{V_D}{\eta^* V_T}\right)}} <<< 1$$

Equation (3) reduces to $I_R = I_S$

In the reverse bias region, the diode current increases exponentially with increasing reverse voltage, and the diode behaves like a nearly constant-voltage source.

Note: the diode equation is an approximation and does not account for all possible diode behaviors, such as temperature effects or reverse breakdown.

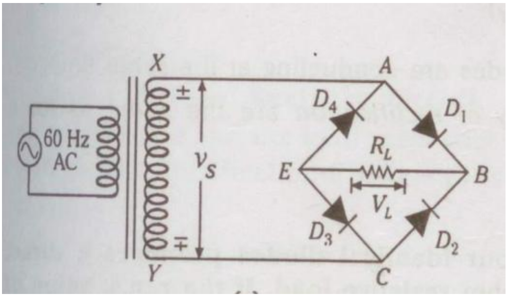
Application: **Bridge Rectifier**

A bridge rectifier is an electronic circuit that converts an alternating current (AC) voltage into a direct current (DC) voltage. It consists of four diodes connected in a bridge configuration that allows the current to flow in one direction, regardless of the polarity of the AC input voltage.

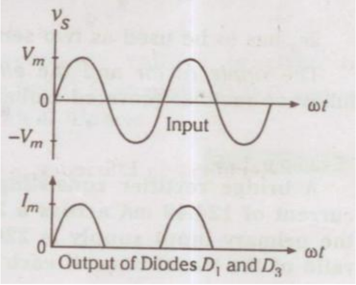
The AC voltage is applied across the two input terminals of the bridge rectifier. Each pair of diodes conducts in turn, allowing the current to flow in only one direction through the load. This process of converting AC to DC is called rectification.

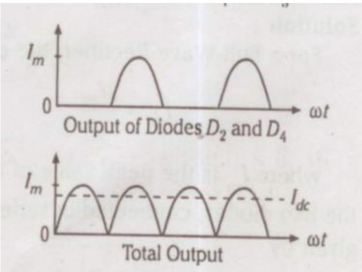
The advantage of using a bridge rectifier over a half-wave rectifier (which uses only two diodes) is that the former provides a higher output voltage and efficiency, as it uses the entire cycle of the AC input voltage. This makes it a commonly used component in power supplies for electronic devices and in many other applications where DC power is needed.

Bridge rectifiers are in the same class of electronics as half-wave rectifiers and full-wave rectifiers. Figure shows such a bridge rectifier composed of four diodes D_1, D_2, D_3, and D_4 in which the input is supplied across two terminals A and C in the figure while the output is collected across the load resistor R_L connected between the terminals E and B.



During the positive input half cycle, terminal X of the secondary is positive and terminal Y is negative. Diodes D_1 and D_3 become forward biased (ON), where as D_2 and D_4 are reverse-biased (OFF). Hence current flows along XABECY producing drop across R_L. During the negative input half cycle, secondary terminal Y becomes positive and X becomes negative. Now D_2 and D_4 are forward biased and current flows along YCBEAX. Thus, we see that current passes through the load resistance R_L in the same direction (BE) during both the half cycles of ac input supply. The output voltage across R_L is shown in figure.





Breakdown mechanism in diodes:

An ordinary p-n junction diode does not conduct when it is reverse biased, if the reverse bias is increased and exceeds a threshold value the junction breaks down and starts conducting heavily. This critical value of the voltage is called breakdown voltage of the junction.

The breakdown voltage depends on the width of the depletion region and doping levels of p and n regions. This can occur through mechanisms such as avalanche breakdown or Zener breakdown, depending on the specific characteristics of the device.

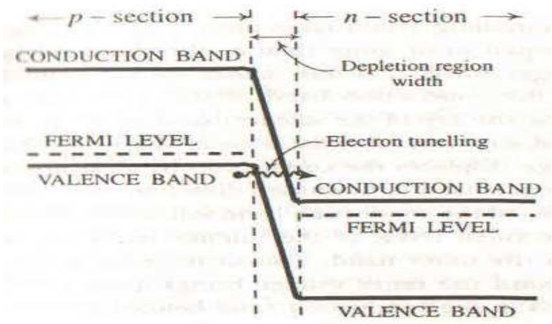
Avalanche breakdown:

Avalanche breakdown is a type of reverse breakdown mechanism that can occur in a p-n junction diode or other semiconductor device. When p and n regions are lightly doped, a breakdown due to avalanche effect occurs in a crystal. In a reverse bias condition, the current in the circuit is mainly due to minority carriers. These carriers fall down the potential barrier and acquire energy. The charge carriers collide with the crystal ions and impart their energy to it in the process. If the reverse voltage is increased further accelerates minority carriers across the junction. The velocity of the minority carriers is proportional to the bias voltage. The accelerated minority carriers acquire sufficient kinetic energy to knock off electrons by disrupting the covalent bonds during collision in the depletion under the influence of external electric field and causes further ionisation of more atoms resulting in a chain reaction. This cumulative effect is known as avalanche breakdown. This creates a self-sustaining avalanche effect that leads to a rapid increase in current flow through the device.

Zener breakdown

When the p and n regions are highly doped, breakdown in a junction occurs even by applying a small reverse voltage across the junction. This sets up a very high electric field across the narrow depletion region and ruptures the covalent bond of atoms and creates electron –

hole pairs leading to sharp increase in the reverse current such a breakdown is known Zener breakdown.



This breakdown does not involve collisions of carriers with the ions of the crystal, as in the case of avalanche effect. This results in a voltage drop across the diode that remains relatively constant, making Zener diodes useful for voltage regulation and other applications**.**

Zener diode as voltage regulator:

Zener diode is a semiconductor diode specially designed to operate in the breakdown region of reverse bias. By varying the impurity concentration and other parameters, it’s possible to design the breakdown voltage to suit specific applications

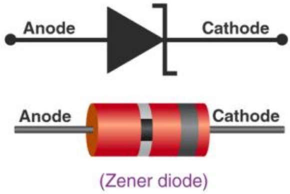
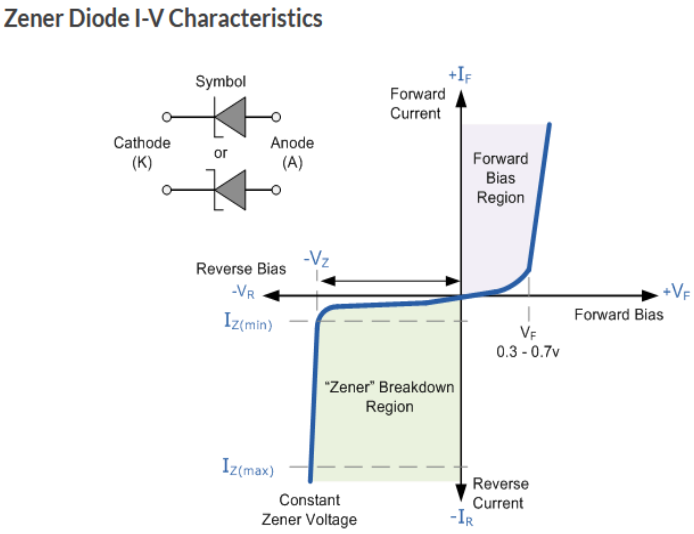


Figure: Schematic representation of zener diode

Zener diode works similar to ordinary diode under forward bias condition. However, the reverse bias characteristic is different from that of an ordinary diode.

A zener diode is a type of diode that is designed to operate in the reverse-bias breakdown region. When a zener diode is reverse-biased and the applied voltage reaches a certain value known as the breakdown voltage, the diode starts conducting current in the reverse direction. The voltage at which the sudden increase in reverse current occurs is called zener breakdown voltage or zener voltage (V_Z).



Zener diodes can be used as voltage regulators because they are able to maintain a nearly constant voltage level even when the input voltage varies over a wide range. Voltage regulation is a measure of a circuit's ability to maintain a constant output voltage when either input voltage or load current varies.

The circuit arrangement is as shown in the figure 8. The power supply provides the input voltage (V_i) and R is the current limiting resistor.

The load resistor (R_L) is connected in parallel with the diode across which constant output is desired.

The total current I passing through R equals the sum of diode current and load current ($I = I_z + I_L$)

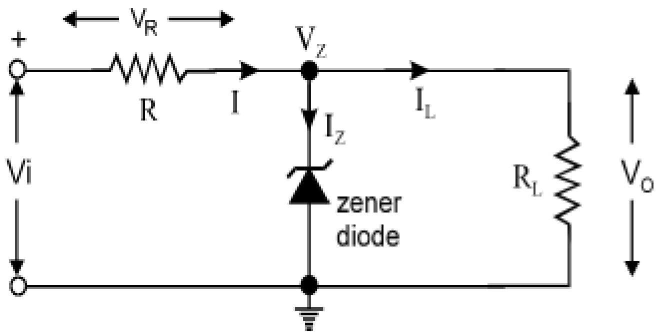


Figure 8 : Circuit diagram

This circuit makes use of the fact that under reverse bias breakdown voltage, the voltage across the zener diode remains constant even if larger current drawn. Since the resistance R_L is parallel to the zener diode, the voltage across the load resistance does not vary even though the current through the load changes. Hence, the voltage across the load is regulated against the variations in the load current.

Operation:

Case 1: We assume that the load resistance R_L is constant and V_i is varying.

As R_L is constant, I_L is also constant because $I_L= V_Z / R_L$. But supply current keeps changing due to change in V_i. The current through R is $I = \frac{V_i - V_z}{R}$ and is the sum of $I = I_z+I_L$.

If V_i increases, then the current I will increase. But as V_z and R_L are constant, the load I_L will remain constant. Naturally, the increase in current will increase zener current I_Z. Thus, the increase in

I will be absorbed by the zener diode without affecting I_L. The increase in V_i results in a larger voltage drop across R by keeping V_o as constant.

If V_i decreases, I will decrease causing I_z to decrease. The diode takes a smaller current and voltage drop across R is reduced. As a result the output V_o remains constant. Thus, whenever V_i changes I and IR drop is such a way as to keep V_o constant.

Case 2: We assume that V_i is constant and the load resistance R_L is varying.

If R_L decreases then I_L will increase. But as I is constant, the zener current will decrease thereby keeping I and IR drop constant. The output voltage remains constant.

If R_L increases then I_L will decrease. With decrease in I_L, the zener current I_Z will increase in order to keep I and IR drop constant. Again, the output voltage remains constant.